

AERONAUTICS

TENTH ANNUAL REPORT

OF THE

**NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS**

1924

INCLUDING TECHNICAL REPORTS
Nos. 186 to 209



WASHINGTON
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LETTER OF SUBMITTAL

To the CONGRESS OF THE UNITED STATES:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I submit herewith the tenth annual report of the committee, for the fiscal year ended June 30, 1924.

The attention of the Congress is invited to Part V of the committee's report, presenting a summary of the present status of aviation with reference to the existing governmental organization, the agencies for coordination, and the relation of aeronautical research, the aircraft industry, and commercial aviation to the problems of national defense. I concur in the committee's general recommendations, and agree that in the last analysis substantial progress in aviation is dependent upon the continuous prosecution of scientific research.

When the National Advisory Committee for Aeronautics was established by Congress in 1915, there was a deplorable lack of technical information on aeronautics in this country. In submitting this, the tenth annual report of the committee, I feel that it is appropriate to say a word of appreciation of the high-minded and patriotic services of the men who have faithfully served their country without compensation as members of this committee and of its subcommittees. Through this committee the talent of America has been marshaled in the scientific study of the problems of flight, with the result that to-day America occupies a position in the forefront of progressive nations in the technical development of aeronautics. The status of the committee as an independent Government establishment has largely made possible its success.

CALVIN COOLIDGE.

The WHITE HOUSE,
December 8, 1924.

LETTER OF TRANSMITTAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., November 24, 1924.

Mr. PRESIDENT:

In compliance with the provisions of the act of Congress approved March 3, 1915 (Public, No. 273, 63d Cong.), I have the honor to transmit herewith the Tenth Annual Report of the National Advisory Committee for Aeronautics, including a statement of expenditures for the fiscal year ended June 30, 1924.

There has been steady progress in the methods and results of scientific research in aeronautics, and consequent continuous, although gradual, development of aviation generally. Aviation is a vital necessity for military and naval purposes. Its development for commercial purposes is highly desirable, and will prove as revolutionary as the automobile; but there are limitations on aircraft performance to-day which must be overcome before commercial aviation can make its own way without subsidy from the Government. Aircraft must be made safer and more controllable at low speeds incident to taking off and landing, and less expensive in initial cost as well as in the cost of maintenance and operation.

Attention is invited to Part V of the report, presenting a statement of "The present status of aviation." The committee has there outlined the present state of technical development, the activities of the governmental agencies concerned, the existing scheme of cooperation, and the policy of the Army and Navy relating to aircraft. It has also touched upon the relation of aeronautical research, commercial aviation, and the aircraft industry to national defense, and emphasized the increasing importance of aircraft in warfare, the need for continuous scientific research, and for the continuous development of aviation for military and naval purposes.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
CHARLES D. WALCOTT, *Chairman.*

The PRESIDENT,
The White House, Washington, D. C.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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GEORGE W. LEWIS, *Director of Aeronautical Research*.
JOHN F. VICTORY, *Assistant Secretary*.

TENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 14, 1924.*

To the Congress:

In accordance with the provision of the act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee submits herewith its tenth annual report. In this report the committee has described its activities during the past year, the technical progress in the study of scientific problems relating to aeronautics, the assistance rendered by the committee in the formulation of policies for the general development of aviation, the coordination of research work in general, the examination of aeronautical inventions, and the collection, analysis, and distribution of scientific and technical data.

Attention is invited to Part V of the report presenting a statement of "The Present Status of Aviation." The committee has there outlined the present state of technical development, the activities of the governmental agencies concerned, the existing scheme of cooperation, and the policy of the Army and Navy relating to aircraft. It has also touched upon the relation of aeronautical research, commercial aviation, and the aircraft industry to national defense, and emphasized the increasing importance of aircraft in warfare, the need for continuous scientific research, and for the continuous development of aviation for military and naval purposes.

This report also contains a statement of expenditures during the fiscal year 1924.

PART I

ORGANIZATION

FUNCTIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915. The organic act charges the committee with the supervision and direction of the scientific study of the problems of flight with a view to their practical solution, the determination of problems which should be experimentally attacked, their investigation and application to practical questions of aeronautics. The act also authorizes the committee to direct and conduct research and experimentation in aeronautics in such laboratory or laboratories, in whole or in part, as may be placed under its direction.

Supplementing the prescribed duties of the committee, its broad general functions may be stated as follows:

First. Under the law the committee holds itself at the service of any department or agency of the Government interested in aeronautics, for the furnishing of information or assistance in regard to scientific or technical matters relating to aeronautics, and in particular for the investigation and study of problems in this field with a view to their practical solution.

Second. The committee may also exercise its functions for any individual, firm, association, or corporation within the United States, provided that such individual, firm, association, or corporation defray the actual cost involved.

Third. The committee institutes research, investigation, and study of problems which, in the judgment of its members or of the members of its various subcommittees, are needful and timely for the advance of the science and art of aeronautics in its various branches.

Fourth. The committee keeps itself advised of the progress made in research and experimental work in aeronautics in all parts of the world, particularly in England, France, Italy, Germany, and Canada.

Fifth. The information thus gathered is brought to the attention of the various subcommittees for consideration in connection with the preparation of programs for research and experimental work in this country. This information is also made available promptly to the military and naval air services and other branches of the Government, and such as is not confidential is immediately released to university laboratories and aircraft manufacturers interested in the study of specific problems, and also to the public.

Sixth. The committee holds itself at the service of the President, the Congress, and the executive departments of the Government for the consideration of special problems which may be referred to it.

ORGANIZATION OF THE COMMITTEE

The committee has 12 members, appointed by the President. The law provides that the personnel of the committee shall consist of two members from the War Department, from the office in charge of military aeronautics; two members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, the United States Weather Bureau, and the United States Bureau of Standards; and not more than five additional persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences. All members as such serve without compensation.

During the past year Maj. John F. Curry, United States Army, was appointed by the President a member of the committee to succeed Maj. Lawrence W. McIntosh, United States Army. This change was made because Major Curry succeeded Major McIntosh as chief of the engineering division of the Army Air Service and it has become a matter of policy to have that official serve as a member of the committee. The President has also appointed to membership on the committee Capt. Emory S. Land, United States Navy, to succeed Commander Jerome C. Hunsaker, United States Navy, who was transferred to duty abroad.

The entire committee meets twice a year, the annual meeting being held in October and the semiannual meeting in April. The present report includes the activities of the committee between the annual meeting held on October 18, 1923, and that held on October 16, 1924.

The organization of the committee at the close of the past year was as follows:

Charles D. Walcott, Sc. D., chairman.

David W. Taylor, D. Eng., secretary.

Joseph S. Ames, Ph. D.

George K. Burgess, Sc. D.

Maj. John F. Curry, United States Army.

William F. Durand, Ph. D.

Capt. Emory S. Land, United States Navy.

Charles F. Marvin, M. E.

Rear Admiral William A. Moffett, United States Navy.

Maj. Gen. Mason M. Patrick, United States Army.

S. W. Stratton, Sc. D.

Orville Wright, B. S.

MEETINGS OF THE ENTIRE COMMITTEE

The semiannual meeting of the entire committee was held in Washington on April 24, 1924, and the annual meeting on October 16, 1924. At these meetings the committee reviewed the general progress in aeronautical research and discussed the problems that should be attacked. Administrative reports were submitted by the secretary and by the Director of the Office of Aeronautical Intelligence. Doctor Ames, chairman of the executive committee, made complete reports on the research work in progress under the committee's direction at the Langley Memorial Aeronautical Laboratory at Langley Field, Va.

At the semiannual meeting, General Patrick made an address on the activities of the Army Air Service and the modern uses and recent developments of military aircraft, and exhibited moving pictures showing the recent progress in aviation in the Army. Admiral Moffett also addressed the committee, on the importance of aviation to the Navy, and exhibited moving pictures showing catapult launching, deck landing on the airplane carrier U. S. S. *Langley*, torpedo launching from aircraft, and the *Shenandoah* in flight.

At the annual meeting the committee had as its guests Dr. Hugo Eckener, the German commander of the Navy's German-built rigid airship *ZR-3*, which had just crossed the Atlantic, and members of the crew of the airship, together with members of the General Board of the Navy and other prominent Army and Navy officers. Dr. Eckener answered a number of questions, through an interpreter, regarding airship operation and development.

At this meeting officers of the committee were elected for the ensuing year as follows: Dr. Charles D. Walcott, chairman; Dr. David W. Taylor, secretary; Dr. Joseph S. Ames, chairman executive committee.

THE EXECUTIVE COMMITTEE

For carrying out the work of the Advisory Committee the regulations provide for the election annually of an executive committee, to consist of seven members, and to include further any member of the Advisory Committee not otherwise a member of the executive committee

but resident in or near Washington and giving his time wholly or chiefly to the special work of the committee. The present organization of the executive committee is as follows:

Joseph S. Ames, Ph. D., chairman.
 David W. Taylor, D. Eng., secretary.
 George K. Burgess, Sc. D.
 Maj. John F. Curry, United States Army.
 Capt. Emory S. Land, United States Navy.
 Charles F. Marvin, M. E.
 Rear Admiral William A. Moffett, United States Navy.
 Maj. Gen. Mason M. Patrick, United States Army.
 S. W. Stratton, Sc. D.
 Charles D. Walcott, Sc. D.
 Orville Wright, B. S.

The executive committee, in accordance with the general instructions of the Advisory Committee, exercises the functions prescribed by law for the whole committee, administers the affairs of the committee, and exercises general supervision over all its activities. The executive committee holds regular monthly meetings, and special meetings when necessary.

The executive committee has organized the necessary clerical and technical staffs for handling the work of the committee proper. General responsibility for the execution of the research program in aeronautics approved by the executive committee is vested in the director of aeronautical research, Mr. George W. Lewis. In the subdivision of general duties he has immediate charge of the scientific and technical work of the committee, being directly responsible to the chairman of the executive committee, Dr. Joseph S. Ames. The assistant secretary, Mr. John F. Victory, has charge of administration and personnel matters, property, and disbursements, under the direct control of the secretary of the committee, Dr. David W. Taylor.

SUBCOMMITTEES

The executive committee has organized six standing subcommittees, divided into two classes, administrative and technical, as follows:

ADMINISTRATIVE	TECHNICAL
Governmental relations	Aerodynamics.
Publications and intelligence.	Power plants for aircraft.
Personnel, buildings, and equipment.	Materials for aircraft.

The organization and work of the technical subcommittees are covered in the reports of those committees appearing in another part of this report. A statement of the organization and functions of the administrative subcommittees follows:

COMMITTEE ON GOVERNMENTAL RELATIONS

FUNCTIONS

1. Relations of the committee with executive departments and other branches of the Government.
2. Governmental relations with civil agencies.

ORGANIZATION

Dr. Charles D. Walcott, chairman.
 Dr. S. W. Stratton.
 John F. Victory, secretary.

COMMITTEE ON PUBLICATIONS AND INTELLIGENCE**FUNCTIONS**

1. The collection, classification, and diffusion of technical knowledge on the subject of aeronautics, including the results of research and experimental work done in all parts of the world.
2. The encouragement of the study of the subject of aeronautics in institutions of learning.
3. Supervision of the Office of Aeronautical Intelligence.
4. Supervision of the committee's foreign office in Paris.
5. The collection and preparation for publication of the technical reports, technical notes, and annual report of the committee.

ORGANIZATION

Dr. Joseph S. Ames, chairman.
Prof. Charles F. Marvin, vice chairman.
Miss M. M. Muller, secretary.

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT**FUNCTIONS**

1. To handle all matters relating to personnel, including the employment, promotion, discharge, and duties of all employees.
2. To consider questions referred to it and make recommendations regarding the initiation of projects concerning the erection or alteration of laboratories and offices.
3. To meet from time to time on the call of the chairman, and report its actions and recommendations to the executive committee.
4. To supervise such construction and equipment work as may be authorized by the executive committee.

ORGANIZATION

Dr. Joseph S. Ames, chairman.
Dr. S. W. Stratton, vice chairman.
Prof. Charles F. Marvin.
Dr. David W. Taylor.
John F. Victory, secretary.

QUARTERS FOR COMMITTEE

The headquarters of the National Advisory Committee for Aeronautics are located in the third wing, third floor of the Navy Building, Seventeenth and B Streets NW., Washington, D. C., in close proximity to the Army and Navy services. The administrative office is also the headquarters of the various subcommittees and of the Office of Aeronautical Intelligence.

Field stations of the committee are the Langley Memorial Aeronautical Laboratory, at Langley Field, Hampton, Va., and the office of the technical assistant in Europe, located at the American Embassy in Paris.

The scientific investigations authorized by the committee are not all conducted at the Langley Memorial Aeronautical Laboratory, but the facilities of other governmental laboratories and shops are utilized, as well as the laboratories connected with institutions of learning whose cooperation in the scientific study of specific problems in aeronautics has been secured.

THE LANGLEY MEMORIAL AERONAUTICAL LABORATORY

The greater part of the research work of the committee is conducted at the Langley Memorial Aeronautical Laboratory, which is located at Langley Field, Va., on a plot of ground set aside by the War Department for the use of the committee when Langley Field was originally laid out. Langley Field is one of the most important and best equipped stations of the Army Air Service, occupying about 1,650 acres and having hangar and shop facilities for the accom-

modation of four bombing squadrons, a service squadron, a school squadron, and an airship squadron.

In the committee's laboratory and on the flying field used in connection therewith, the fundamental problems of scientific research recommended by the various subcommittees are investigated. The laboratory is organized with five subdivisions, as follows: Power plants division, wind tunnel division, flight test division, technical service division, and property and clerical division. The administration of the laboratory is under the immediate direction of the engineer in charge, under the general supervision of the officers of the committee.

The laboratory consists of six buildings. A research laboratory building, containing the administrative offices, the drafting room, the machine and woodworking shops, and the photographic and instrument laboratories; two aerodynamical laboratories, one containing a wind tunnel of the open type, and the other a variable density wind tunnel, each unit being complete in itself; two engine dynamometer laboratories of a semipermanent type, both equipped to carry on investigations in connection with power plants for aircraft; and an airplane hangar equipped with a repair shop, dope room, and facilities for taking care of 16 or 18 airplanes.

No large changes or additions of research equipment have been made during the past year. No buildings have been added during the past year, but some major alterations have been effected and routine repairs executed.

The research flight work was carried on with the aid of 11 airplanes which made a total of 918 flights and approximated 297 hours total flying time. One serious accident occurred during the year, which resulted in the death of the junior aeronautical engineer, who was acting as observer, and serious injury to the pilot. This is the first serious accident experienced during approximately six years of active research and it is especially regretted.

Recognition by the Government of the necessity of satisfying the increasing demand for new and accurate knowledge on the fundamental problems of flight has made possible the development of an efficient research organization numbering 92 at Langley Field at the close of the fiscal year 1924. The main research laboratory building has become so overcrowded as to interfere with efficiency and to require the construction of an additional laboratory building. The site for the building has been tentatively determined upon, in the rear of the main building. This construction has been included in the committee's estimates for the fiscal year 1926, and if the necessary funds are appropriated the building should be available during the spring of 1926 to relieve the present present congestion.

OFFICE OF AERONAUTICAL INTELLIGENCE

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral branch of the committee's activities. Its functions are the collection, classification, and diffusion of technical knowledge on the subject of aeronautics to the Military and Naval Air Services and civil agencies interested, including especially the results of research and experimental work conducted in all parts of the world. It is the officially designated Government depository for scientific and technical reports and data on aeronautics.

Promptly upon receipt, all reports are analyzed and classified, and brought to the special attention of the subcommittees having cognizance, and to the attention of other interested parties, through the medium of public and confidential bulletins. Reports are duplicated where practicable, and distributed upon request. Confidential bulletins and reports are not circulated outside of governmental channels.

To efficiently handle the work of securing and exchanging reports in foreign countries, the committee maintains a technical assistant in Europe, with headquarters in Paris. It is his duty to personally visit the Government and private laboratories, centers of aeronautical information, and private individuals in England, France, Italy, Germany, and other European countries, and endeavor to secure for America not only printed matter which would in the ordinary course of events become available in this country, but more especially to secure advance information as to work in progress, and any technical data not prepared in printed form, and

which would otherwise not reach this country. John Jay Ide of New York is the present incumbent.

The records of the office show that during the past year copies of technical reports were distributed as follows:

Committee and subcommittee members.....	1, 683
Langley Memorial Aeronautical Laboratory.....	2, 702
Paris office of committee.....	5, 355
Army Air Service.....	1, 930
Naval Air Service, including Marine Corps.....	3, 517
Manufacturers.....	4, 695
Educational institutions.....	5, 227
Bureau of Standards.....	720
Miscellaneous.....	11, 380
Total distribution.....	37, 209

The above figures include the distribution of 14,704 technical reports, 10,421 technical notes, and 4,504 technical memorandums of the National Advisory Committee for Aeronautics. Three thousand and thirteen written requests for reports were received during the year in addition to innumerable telephone and personal requests, and 15,537 reports were forwarded upon request.

FINANCIAL REPORT

The appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1924, as carried in the independent offices appropriation act approved February 13, 1923, was \$270,000, under which the committee reports expenditures and obligations during the year amounting to \$269,593.33, itemized as follows:

Salaries (including engineering staff).....	\$120, 846. 43
Wages.....	64, 161. 65
Supplies and materials.....	13, 091. 84
Communication service.....	762. 72
Travel.....	8, 172. 24
Transportation of things.....	1, 741. 33
Furnishing of electricity.....	3, 355. 93
Repairs and alterations.....	8, 217. 69
Equipment.....	17, 773. 50
Special investigations.....	31, 470. 00
Expenditures.....	269, 593. 33
Unexpended balance.....	406. 67
Total.....	270, 000. 00

In addition to the above, the committee had two separate appropriations, one of \$13,000 for printing and binding, of which \$7,850.13 was expended; and another of \$24,000 for increase of compensation to employees at the rate of \$240 per annum, of which the committee expended \$19,427.96.

PART II

GENERAL ACTIVITIES

CONSIDERATION OF AERONAUTICAL INVENTIONS

The committee examines and reports upon all aeronautical inventions which are submitted to it for consideration and recommendation.

By virtue of a formal agreement with the Navy Department, inventions of a general character relating to aeronautics which are received in the Navy Department are referred to the National Advisory Committee for Aeronautics for consideration and proper action. The committee examines such inventions, conducts the necessary further correspondence with the inventors, and where a given invention has prospective value the committee makes a report to the Navy Department, a copy of which is sent to the Army Air Service. In like manner, although without a formal agreement, the committee considers inventions referred to it by the Army Air Service, and if any such inventions appear to be promising, a copy of the committee's report to the Army is sent to the Navy in each case.

USE OF NONGOVERNMENTAL AGENCIES

The various problems on the committee's approved research programs are as a rule assigned for study by governmental agencies. In cases where the proper study of a problem requires the use of facilities not available in any governmental establishment, or requires the talents of men outside the Government service, the committee contracts directly with the institution or individual best equipped for the study of each such problem to prepare a special report on the subject. In this way the committee has marshaled the facilities of educational institutions and the services of specialists in the scientific study of the problems of flight.

COOPERATION OF ARMY AND NAVY

Through the personal contact of responsible officers of the Army and Navy serving on the three standing technical subcommittees, a knowledge of the aims, purposes, and needs of each service in the field of aeronautical research is made known to the other. The cordial relations that invariably flow from such personal contact are supplemented by the technical information service of the committee's Office of Aeronautical Intelligence, which makes available the latest technical information from all parts of the world. While a healthy rivalry exists in certain respects between the Army and Navy, there is at the same time a coordination of effort in experimental engineering and a mutual understanding that is productive of the best results.

The Army and Navy Air Services have aided whenever called upon in every practicable way in the conduct of scientific investigations by the committee. Each service has placed at the disposal of the committee airplanes and engines required by the committee for research purposes. The committee desires to record its appreciation of the cooperation given by the Army and Navy Air Services, for without this cooperation the committee could not have undertaken many of the investigations that have already made for substantial progress in aircraft development. The committee desires especially to acknowledge the many courtesies extended by the Army authorities at Langley Field, where the committee's laboratories are located, and to the naval authorities at the Hampton Roads Naval Air Station.

INVESTIGATIONS UNDERTAKEN FOR THE ARMY AND NAVY

As a rule, the technical subcommittees, including representatives of the Army and Navy Air Services, prepare programs of research work of general use or application, and these programs, when approved by the National Advisory Committee for Aeronautics, furnish the problems for solution by the Langley Memorial Aeronautical Laboratory. The cost of this work is borne by the committee out of its own appropriation. If, however, the Army Air Service or the Naval Bureau of Aeronautics desires specific investigations to be undertaken by the committee for which the committee has not the necessary funds, the committee's regulations as approved by the President provide that the committee may undertake the work at the expense of either the Army or the Navy.

The investigations thus undertaken by the committee during the past year may be outlined as follows:

FOR THE BUREAU OF AERONAUTICS OF THE NAVY DEPARTMENT

- Investigation and development of a solid-injection type of aeronautical engine.
- Development of aircraft engine supercharger.
- Distribution of loading between wings of biplanes and triplanes.
- Investigation of planing angles and get-away speeds of seaplanes.
- Investigation of tail vibration and sluggish control of a Navy monoplane.
- Flight tests of superchargers.
- Investigation of landing speed of TS airplane.
- Investigation of aerodynamic loads on the U. S. S. *Shenandoah*.
- Investigations of accelerations and decelerations of airplanes.

FOR THE ENGINEERING DIVISION OF THE ARMY AIR SERVICE

- Full-scale investigation of different wings on the Sperry messenger airplane.
- Investigation of the efficiency of propellers when used in front of obstructions as found in bombing airplanes.
- Investigation of the behavior of an airplane in landing and in taking off.
- Investigation of pressure distribution along the chord of typical wing sections.
- Investigation of pressure distributions and accelerations in order to determine the proper loading to be used in the design of airplanes.

SPECIAL COMMITTEE ON DESIGN OF ARMY SEMIRIGID AIRSHIP "RS-1"

At the request of the Army Air Service, the National Advisory Committee for Aeronautics appointed a special subcommittee to examine and report on the design and construction of the Army semirigid airship known as the *RS-1*. This special subcommittee was organized on February 15, 1923, as follows:

- Henry Goldmark, chairman.
- W. Hovgaard.
- Max M. Munk.
- L. B. Tuckerman.
- W. Watters Pagon, secretary.

The *RS-1* is a semirigid type airship, 300 feet in length, 71 feet in diameter, and has a capacity of 700,000 cubic feet. The contract for the design and construction of the airship was awarded by the Army Air Service to the Goodyear Tire & Rubber Co.

Following the organization of the subcommittee, one of the first meetings was held at the Goodyear Tire & Rubber Co. at Akron, Ohio. Here the members had an opportunity of thoroughly acquainting themselves with details of the design and construction of the airship. During the first meetings the discussions were largely confined to the specifications of the Army Air

Service for the construction of the *RS-1* airship with regard to the design, fabrication, and the flight performance.

Following the meeting at Akron, the committee confined its activities to the technical questions of design and safety of the *RS-1*. Many of the special problems were studied by separate members of the committee, who reported to the committee at their meetings. One important problem requiring detailed investigation was the problem of sufficient strength of the nose cap and its attachment to the keel structure. Investigation showed that a nose cap strong enough to withstand external forces, with a zero pressure in the envelope, was not feasible on account of the weight required in the structure. A very satisfactory design was agreed upon and has been completed, requiring, however, a small pressure to be maintained inside the envelope.

Another problem considered was the "breathing stresses." The problem was how the load and bending moments created were distributed to the envelope and to the keel structure. It is safe to say that both the keel and envelope take a portion of the load, but it is safer to make the keel strong enough to take the total load.

The problem of obtaining the stresses in the keel, especially considering the possibility of the changes in the shape of the envelope throwing additional stresses on the keel, does not lend itself to reliable mathematical analysis. At the request of the committee the Army Air Service has had constructed a special model of the *RS-1* including the keel structure. This water model will be tested at McCook Field in the near future and it is expected that the results of the test will give numerical information with reference to the stresses in the keel and envelope with changing pressures. This is the first known test of this kind on a water model of an airship with a model of an elastic keel attached.

AMERICAN AERONAUTICAL SAFETY CODE

The purpose of the American Aeronautical Safety Code is to establish uniform safety standards for the construction and maintenance of aircraft and for their operation and flight, especially at airdromes. The work is being pursued according to the scheme of procedure of the American Engineering Standards Committee, which in 1920 recognized the Bureau of Standards and the Society of Automotive Engineers, Inc., as joint sponsors for this project. A sectional committee was formed by inviting representation from the following organizations:

- Aeronautical Chamber of Commerce.
- American Institute of Electrical Engineers.
- American Society of Mechanical Engineers.
- American Society for Testing Materials.
- American Society of Safety Engineers.
- Manufacturers Aircraft Association.
- National Aeronautic Association.
- National Aircraft Underwriters Association.
- National Advisory Committee for Aeronautics.
- National Safety Council.
- Rubber Association of America.
- Underwriters Laboratories, Inc.
- United States Coast Guard.
- United States Forest Service.
- United States Navy Department.
- United States Post Office Department.
- United States War Department.
- United States Weather Bureau.

To facilitate the development of the code, the subject matter of which it will treat was divided into parts as follows:

Introductory part.—Scope.

Part 1.—Airplane structure, design, fabrication, and tests.

- Part 2.—Power plants, design, assembly, and tests.
- Part 3.—Equipment, maintenance, and operation of airplanes.
- Part 4.—Signals and signaling equipment.
- Part 5.—Airdromes and airways.
- Part 6.—Traffic and pilotage rules.
- Part 7.—Qualifications for airmen.
- Part 8.—Balloons.
- Part 9.—Airships.
- Part 10.—Parachutes.

The sectional committee in its organization meeting held on September 2, 1921, in New York City, constituted five working subcommittees, the members of which were not limited to members of the sectional committee, and assigned to each of these subcommittees one or more of the various parts listed above for development.

Reports of all the subcommittees have been received and considered by the sectional committee and ordered printed as advance drafts for general distribution. These parts have not been adopted by the sectional committee having general charge of the formulation of the code and are subject to revision pending such adoption.

It is to be expected that the application of aeronautics to commercial use will develop more surely when the experimental stages in its progress are passed and a fund of generally acceptable standards is established.

To insure this development it is desirable not only to establish practice along lines which are safe, but to have that practice as uniform as possible throughout the entire Nation, since the art is one involving flights over extensive reaches of territory.

The Aeronautical Safety Code will serve as a standard of safe practice for aircraft users and manufacturers and will be available as a guide to legislative regulation. It is hoped that such regulatory legislation as may be necessary will eventually be national in scope, but should national legislation fail and local regulations be set up, it is believed that the code will aid materially in securing uniformity in legislation.

STANDARDIZATION OF WIND TUNNEL RESULTS

The standardization tests authorized by the National Advisory Committee for Aeronautics have been under way during the past year, the models, consisting of three cylinders, having a length ratio of 5:1 and four models of the U. S. A. 16 airfoil section, each having an aspect ratio of 6:1 and a length varying from 18 to 36 inches, have been tested at the Langley Memorial Aeronautical Laboratory, the Washington Navy Yard, Bureau of Standards, and some tests completed at McCook Field and Massachusetts Institute of Technology.

The tests were conducted by all the wind tunnels on both the cylinders and airfoil models under as wide a range of V/L as possible and including the determination of lift, drag and pitching moment for every 4° from -4° to $+20^\circ$.

An exact model of the National Physical Laboratory airship model has been completed and is ready for test in the committee's variable density wind tunnel at Langley Field. The report on this test will be a valuable addition to the report presented to the National Physical Laboratory on the comparative tests made in the wind tunnels of the United States. The National Physical Laboratory standard model of an R. A. F. 15 airfoil has been tested in the wind tunnels of this country and returned to England. A report giving the results of the comparative tests in this country is in preparation.

CANADA'S CONTINUED COURTESY TO AMERICAN AIR PILOTS

In May, 1920, Canada promulgated regulations permitting United States qualified aircraft and pilots to fly in Canada for a period of six months on the same basis as if the United States had established its regulations as contemplated under the Convention for the Regulation of International Air Navigation. The Government of the United States has not as yet ratified this

convention. Canada, however, has from time to time extended for periods of six months or a year the regulations favoring American air pilots, the latest extension expiring May 1, 1925. The Government of the United States has expressed appreciation to the Government of Canada for these repeated courtesies. The proper remedy for the resulting unsatisfactory situation is either for the United States to ratify the Convention for the Regulation of International Air Navigation or to negotiate a separate treaty with Canada for the regulation of air traffic between the two countries. Neither of these remedies, however, could be effective in the absence of an agency for the regulation of civil air navigation in the United States.

PART III

REPORTS OF TECHNICAL COMMITTEES

REPORT OF COMMITTEE ON AERODYNAMICS

ORGANIZATION

The committee on aerodynamics is at present composed of the following members:

Dr. Joseph S. Ames, Johns Hopkins University, chairman.
Commander H. C. Richardson, United States Navy, vice chairman.
Dr. L. J. Briggs, Bureau of Standards.
Capt. Gerald E. Brower, United States Army, engineering division, McCook Field.
Lieut. W. S. Diehl, United States Navy.
Mr. H. N. Eaton, Bureau of Standards.
Maj. Clinton W. Howard, United States Army, engineering division, McCook Field.
Mr. G. W. Lewis, National Advisory Committee for Aeronautics.
Prof. Charles F. Marvin, Chief Weather Bureau.
Prof. Edward P. Warner, Massachusetts Institute of Technology, secretary.
Dr. A. F. Zahm, United States Navy.

FUNCTIONS

The functions of the committee on aerodynamics are as follows:

1. To determine what problems in theoretical and experimental aerodynamics are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding aerodynamic investigations and developments in progress or proposed.
4. The committee may direct and conduct research in experimental aerodynamics in such laboratory or laboratories as may be placed either in whole or in part under its direction.
5. The committee shall meet from time to time on the call of the chairman and report its action and recommendations to the executive committee.

The committee on aerodynamics by reason of the representation of the various organizations interested in aeronautics is in close contact with all aerodynamical work being carried out in the United States. In this way the current work of each organization is made known to all, thus preventing duplication of effort. Also all research work is stimulated by the prompt distribution of new ideas and new results, which add greatly to the efficient conduction of aerodynamic research. The committee keeps the research workers in this country supplied with information on all European progress in aerodynamics by means of a foreign representative who is in close touch with all aeronautical activities in Europe. This direct information is supplemented by the translation and circulation of copies of the more important foreign reports and articles.

The aerodynamic committee has direct control of the aerodynamical research conducted at Langley Field, the propeller research conducted at Leland Stanford University under the supervision of Dr. W. F. Durand, and some special investigations conducted at the Bureau of Standards and at a number of the universities. The investigations undertaken at the Washington Navy Yard aerodynamical laboratory, the engineering division, Army Air Service, the Bureau of Standards, and the Massachusetts Institute of Technology are reported to the committee on aerodynamics.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

ATMOSPHERIC WIND TUNNEL RESEARCH—*Airfoils*.—The investigation of the distribution of load between the individual wings of biplanes and triplanes, which was made last year at the request of the Bureau of Aeronautics of the Navy Department, has been continued in a series of tests on thick airfoils (U. S. A. T. S. 5) for the purpose of checking the former work on thin sections (R. A. F. 15). The most important conclusion drawn from this work is the fact that the total load on a biplane or triplane cellule may be considered, for all practical design purposes, as equally divided among its component wings under all conditions in which accelerations become dangerously high.

The determination of the pressure distribution over thick, tapered airfoils, carried out at the request of the Army Air Service, is almost complete. Three representative models (N. A. C. A. 81, U. S. A. 35 and U. S. 27C mod.), built up of laminations and inlaid with hypodermic tubing, have been tested. The fourth member of this series, a model of the upper wing of a Fokker D-VII airplane, complete with aileron and overhanging horn balance, is now being prepared for test. Pressures will be measured over wing tip, aileron, and balance. The regularity and known precision of simultaneous observations at all points and the great saving of time in actual testing have well justified the more difficult construction. This information is of paramount importance for the design and stress analysis of airplanes using wings of this type.

The effects of shielding the tips of airfoils by means of thin plates, affixed to the wing tips in planes perpendicular to the span, have been studied. A considerable improvement of characteristics was obtained, particularly with respect to climb. This aerodynamic improvement is equivalent, in effect, to increasing the aspect ratio.

The motion and forces upon an airfoil, oscillating in pitch about an axis some distance upstream from its own leading edge, have been studied by an entirely new method. The oscillating system is connected to a chronograph which records the motion on a time base; from the graphical record and a determination of inertia the instantaneous forces on the airfoil can be calculated. It appears from the results that the time lag involved in building up the lift during change of angle of attack is small and can be neglected in many cases.

Model airplanes.—Very complete tests have been made on an Army Air Service (Sperry) messenger airplane, successively equipped with six sets of wings of different profiles. The lift and drag of the model, with proper elevator settings to give balance in level flight, have been determined throughout the flying range. All tests were made at both 40 m. p. h. (17.9 m/s) and 78.4 m. p. h. (35 m/s). The necessity of testing at high speeds has been very clearly shown by these experiments. The work done in the atmospheric tunnel will be compared with similar tests to be made in the variable density tunnel and with the free flight tests now being carried on. This research is expected to furnish much valuable information on the relation between model and full-size airplane characteristics.

Tests of aerodynamic instruments.—A large number of tests have been made to determine the merits of various types of orifices intended for the measurement of pressure over the hulls and control surfaces of airships. Several types were found satisfactory.

Accurate determinations of airspeed in flight are made by means of a Pitot tube which is located in the nose of a streamlined body hung at a considerable distance below the airplane or airship. This procedure eliminates the error caused by local disturbances around the aircraft but we still have to deal with the interference of the streamlined body on the tube. A study of this interference has been made in the wind tunnel, a very good streamline shape developed in the process, and, by proper proportioning of the apparatus, it has been found possible to reduce the interference effect to a small fraction of 1 per cent.

During this work on Pitot tube interference a certain very peculiar effect was discovered when a disk was used as the interfering body. Preliminary tests under various conditions indicate this combination to be extremely sensitive to changes in turbulence, and it is probable that a very simple and accurate "turbulence meter" may be developed on this basis.

The wind tunnel has been used to calibrate a number of recording flight instruments and also to locate the aerodynamic axes of yaw tubes and flight path inclinometers.

Miscellaneous.—Tests have been made to determine the lift (cross wind force) and drag on rotating cylinders of Greek cross and circular cross section; the same forces were measured in the case of a compound strut of which the upstream portion was constituted by rotating circular cylinder. With the circular cylinder, lift coefficients as high as 9.5, computed on projected area, and ratios of lift to drag of 7.8 were obtained. Numerous unforeseen conditions appeared during these tests; several phenomena remain unexplained.

Apparatus and methods for the photography of air flow patterns, visualized by the introduction of smoke filaments, have been developed and are being used advantageously in the study of many problems. While the visualization of air flow by means of smoke has long been used as a demonstration device, newly developed technique is making of it a recognized research instrument.

A model of the horizontal tail surfaces of a service airplane, which was known to suffer from excessive vibration of the entire empennage, was built up of three parts by attaching the halves of the elevator to the stabilizer by means of elastic wire hinges. The stabilizer was so mounted as to be free in roll and was fitted with springs to provide restoring moments. Exposed to the tunnel airstream, the model was found to oscillate violently at almost any combination of air speed and angle of attack. The position of the elevators seemed of little importance. Two methods of preventing these oscillations were found. With the two halves of the elevator rigidly connected, it became impossible to set up any oscillation which induced rolling in the stabilizer as before. The conditions here so resembled those under which the Baumhauer-Koning wing-flutter effect was found that its remedy was also applied and found to eliminate the vibration. This consisted in applying forward-hung masses to the independent halves of the elevator, thus bringing their centers of gravity forward of the hinge line. With this modification it was found possible, but only by a violent disturbance, to start an oscillation of the original character; however, the damping was so heavy that the oscillation disappeared almost immediately.

VARIABLE-DENSITY WIND TUNNEL—Tunnel development.—The variable-density tunnel has been operated continuously throughout the year with occasional interruptions for minor changes which have been found necessary or desirable in developing the tunnel into an accurate piece of research apparatus. Considerable attention has, of necessity, been given to such matters as balance alignment and calibration, a survey of the air flow, and the overcoming of operating difficulties.

The balance has been carefully calibrated and can be relied upon to measure lift forces to an accuracy of plus or minus 10 grams and drag forces to an accuracy of plus or minus 1 gram. This is considered satisfactory, especially as the balance was designed for large forces and has actually been called upon to measure lift forces as great as 90 kilograms and drag forces as great as 20 kilograms.

The air flow in the tunnel has been further improved by a lengthening of the entrance cone and by the installation of a new honeycomb upstream of the experiment section. The air flow at the throat was even then not quite uniform, but it was found possible to improve the velocity distribution by increasing the resistance of the honeycomb at those points where the velocity was too high. The velocity variation at the model position is now within plus or minus 1 per cent.

Among the problems which have arisen in connection with operating the tunnel, there may be mentioned the breaking of the model-supporting wires at loads much below their tensile strength. This offered an obstacle to operation at one time, but the difficulty has been overcome.

In the operation of the variable-density tunnel it has been found convenient to extend the scale of the tests not only to a much higher Reynolds number than is possible in the atmospheric tunnel but to a lower one also by exhausting the air from the tank. Satisfactory opera-

tion is secured over a range of tank pressures from $\frac{1}{12}$ to 20 atmospheres. In general, metal air foils are to be used exclusively in this tunnel because of the high forces to be measured.

Research.—Tests have been made on a wooden airship model through a range of tank pressures from $\frac{1}{12}$ to 14 atmospheres. Although it was not possible at the time these tests were made to operate at the full tank pressure of 20 atmospheres, and the scale reached is far short of full scale, data were obtained up to a scale eight times as great as is possible in the atmospheric tunnel. These results are interesting in that they show the tendency of the drag coefficient of an airship model to approach a constant value at the higher Reynolds numbers, this value being approximately the same as that found following the dip in the drag curve obtained in the atmospheric tunnel.

A program of tests of surface friction on flat plates was carried out under various conditions of flow, as parallel, divergent, and convergent with respect to the plate and at various pressures. The flow over the whole surface of the plate was found to be erratic, partly laminar, and partly turbulent. For this reason, the tests were discontinued. They will be taken up again after more information on the type of surface flow has been obtained.

Tests on a group of 36 air foils are now in progress, constituting an investigation of scale effect on air foils and a study of the characteristics of a systematic series of air foils at high Reynolds numbers. Results obtained on two characteristic sections indicate that the maximum lift coefficient increases at the higher pressures in the case of the strut section but remains nearly constant in the case of the cambered section. The minimum drag coefficient is less at the higher pressures for both sections, and the maximum lift to drag ratio is consequently higher for both.

The results so far obtained in the variable-density tunnel give every reason to believe that the results obtained with an airplane model will be directly comparable to those obtained on the full-sized airplane in flight.

FLIGHT RESEARCH—Airships.—The investigation of the pressure distribution at 400 points over the hull and tail surfaces of an airship in flight, mentioned in last year's report, has been completed. The distribution of load over the airship for some thirty conditions of flight has been determined, and the results are available in the form of curves representing the loads on the tail surfaces, the loads on the envelope, and a combination of the two. This research is the most extensive of its kind attempted on an airship, and the data obtained are extremely valuable for purposes of stress analysis and calculations. In connection with the same research a photographic method of obtaining the turning characteristics of an airship was developed, by which it is possible to secure much more complete and accurate information of the behavior of an airship in turning flight than previously.

In the light of the experience and information gained on the *C-7* airship, and elaborate research program, including pressure distribution, turning trials, and acceleration tests, has been prepared for the U. S. S. *Shenandoah*. New measuring instruments have been designed and are being constructed especially for this pressure-distribution work which will allow simultaneous readings of a much larger number of pressures and will provide continuous records of these pressures.

Airplanes.—Within the last year considerable progress has been made in determining the nature of the air flow over the wings and other component parts of an airplane in flight. An investigation of this nature conducted on a service airplane known to have certain peculiarities in flight showed that many of its undesirable characteristics were caused by an unusually turbulent air flow over parts of the wings and fuselage. The method used, that of discharging a stream of smoke in advance of the airplane at the desired place and photographing its flow over that part of the airplane, presents an extremely simple and effective manner of determining the air flow and opens up a very interesting and valuable field of investigation, especially with regard to making improvements in airplanes in present use.

In order to obtain a comparison of full-scale and model planing characteristics with a view to improving the methods of obtaining the latter, the laboratory has been conducting tests on

three representative types of seaplanes; single-float, twin-float, and boat type. The work has been completed on the single-float-type seaplane and is at present being conducted on the boat type. Preparations are in progress for tests to determine the water pressures on the bottom of a seaplane float during various kinds of take-off, landing, and taxiing maneuvers.

A previous investigation conducted by the laboratory on the landing and take-off characteristics of an airplane proved to be of such value that the Army Air Service requested a similar research embracing most of the service-type airplanes. This will provide material which will be of value in connection with the improvement of those characteristics in new design and which will also be suitable for use in instructing student pilots prior to actual flight training. This investigation is under way now and consists of determining the acceleration, control position, angle of attack, run on the ground, and air speed for each airplane in various types of take-offs and landings.

The subject of load distribution on high-speed airplanes is of particular importance at the present time due to recent failures occurring in flight on this type of aircraft. These failures lead to the conclusion that the present method of load computation is not justified by actual conditions and that to develop new rules more complete data are necessary than are now available from past pressure-distribution tests. The laboratory is now conducting an investigation in which the pressures obtained in violent maneuvers on a representative section of both the wings and tail surface are simultaneously recorded. The accelerations obtained are larger than in any previous pressure distribution investigation, and the results should give much valuable information pertinent to the loading problems.

Flight tests are now in progress on the Sperry Messenger airplane equipped with six sets of interchangeable wings, each of different airfoil section, namely, U. S. A. 5, U. S. A. 27, U. S. A. 35, U. S. A. 35B, R. A. F. 15, and Gottingen 387. This research is being carried on in conjunction with wind-tunnel tests to determine the nature and magnitude of the scale effect.

Propellers.—During the past year flight tests on a series of seven propellers were carried out at the laboratory in conjunction with model tests of the same propellers at Stanford University, the purpose of which was primarily to establish a relation between the performance of full-scale propellers in flight and model propellers in the wind tunnel. The propeller characteristics in flight have been determined and, although the results of the model propeller tests are not fully available as yet, such comparison as it has been possible to make indicates a remarkably good agreement between the full-scale and model results. Incident to the propeller-flight tests much data was obtained on the performance of the VE-7 airplane when equipped with each of the seven propellers.

Performance tests.—Because of the special facilities, both trained personnel and recording instruments, available at the Langley Memorial Aeronautical Laboratory for making accurate performance tests of airplanes, more work of this nature is being requested by other departments and executed by the laboratory each year. Experience with several methods of reducing flight data to the conditions of standard atmosphere has led to the formulation and adoption of a new method which is much simplified and yet sufficiently accurate for any purpose served by such reduced data.

INSTRUMENT RESEARCH AND DEVELOPMENT.—Although several new instruments have been developed, progress in this important activity has consisted mainly in the addition of many instruments of the standard types and in the general improvement of the recording instruments with reference to ease of manufacture, interchangeability, convenient operation, and reliability. The standard film drum, which is used on most of the recording instruments, has been materially improved. The changes will not only save time in the loading and unloading of the film but will also eliminate failures due to faulty loading and will considerably reduce the maintenance work required. In addition to instruments for our own use, three accelerometers have been made for the Navy for use in the study of catapult and landing apparatus for airplane carriers.

The automatic observer developed last year has been entirely redesigned, the weight and bulk being considerably less than for the original model. The camera fastenings and operating mechanism have been changed to facilitate the installation and removal of the camera, to simplify

this operation, and to increase the frequency of the record. An added device serves to synchronize the records with those made by other instruments. A motor-driven pyrometer selector switch provides means for making a number of temperature measurements at various points on an airplane engine. The liquid-type, recording-multiple manometer, such as was used on the "C" class airship pressure-distribution investigation, has been redesigned, the new apparatus being capable of simultaneously recording over 200 different pressures. The records are made on a standard size of photostat paper and may be made somewhat faster than one complete set per second. This instrument is not appreciably affected by such inclinations and accelerations as are experienced in airship work and will save considerable time both in the installation of the apparatus and in the working up of the records.

Among the new instruments which have been developed are the camera-obscura shutter and the electric chronometric timer. The first instrument is a focal plane shutter operated by a constant-speed motor and is used in connection with the photography of airship maneuvers by means of the camera obscura. The chronometric timer is an instrument containing a standard N. A. C. A. constant-speed electric motor which drives electric contactors whose opening and closing are timed by a standard watch escapement. The apparatus automatically controls the timing light circuits of several recording instruments, thus synchronizing and definitely timing the records. A successful new adaptation of an old instrument was made during the year in the use of our standard air speed recorder as an intake manifold pressure recorder. In connection with the propeller research it was possible with this instrument to obtain flight records from which the engine-power output could be determined upon the basis of a previous dynamometer calibration of the engine and instrument.

There are in process of development and manufacture several new instruments, such as the 60-capsule, continuous-recording manometer, a recording tachometer, an electric gyroscope, and a short-period sensitive galvanometer. The 60-capsule recording manometer is being developed for use in connection with the study of pressure distribution on large airships such as the *Shenandoah* or the *ZR-3*, and, besides recording a greater number of pressures than our older type of continuous-recording manometer, this instrument will make longer individual records and will contain film enough for many records without the necessity of reloading. It will also embody detail improvements to eliminate the difficulty of manufacture and adjustment experienced in previous types. The recording tachometer will consist primarily of a centrifugal pump, the discharge head from which will be recorded by a standard recording manometer and will be a measure of the engine speed. The development work on the electric gyroscope and galvanometer is being carried out for the N. A. C. A. by the Bureau of Standards. The gyroscope will be incorporated in instruments for the recording of angular velocities, and the galvanometer will be used for recording phenomena which can best be handled by electrical means.

AERODYNAMIC THEORY

The theory of steady motion of a solid in a perfect fluid has been amplified and extended until it now covers about all of the particular fields in which its application is practical. The steps which have led to the present state of knowledge are worthy of consideration. First, the theoretical treatment of perfect fluids was made by Helmholtz, Lamb, and others. Lanchester developed a theory of airfoil lift and drag which was substantially correct, but on account of the method of presentation it was not generally accepted. Fuhrmann and Prandtl demonstrated that air could successfully be represented by a perfect fluid when they found the measured pressure distribution on airship models to be in satisfactory agreement with the calculated values, particularly in the region near the bow.

Prandtl's work in this connection proved to be the beginning of a new era in theoretical aerodynamics. Kutta, Joukowski, and others, utilizing the method of orthogonal transformations, succeeded in calculating airfoil lift for certain special wing sections. The mathematical work required was very great and the sections were not general, thus limiting the method to a classroom exercise for advanced students of mathematics. The next advance was made

at Gottingen, where Prandtl, Munk, and Betz developed a theory of wing lift based on Prandtl's vortex theory. This theory had immediate application and has been very well received.

During the last three years Doctor Munk has been developing a new general theory for steady motion in a perfect fluid, in order to eliminate the objections to the use of vortices, which are not altogether real, and in order to obtain numerical methods for practical use. The new theory is based on the simple conceptions of "apparent mass" and "kinetic energy" of flow, and while it gives the same results obtained by the use of vortices the mathematical treatment is much simplified. The most important applications of this new theory have been to the calculation of lateral forces on airship hulls in various conditions of flight and to the computation of the lift and moment of any practical wing section within the useful range of its angle of attack.

Doctor Munk has also made an important contribution to the science of aerodynamics in his analysis of propellers. In this he abandons the blade element theory and considers the blades as a unit. This method of attack leads to some interesting results, particularly for purposes of comparison.

During the past year some interesting and valuable work has been done in England and France toward checking the theories of Prandtl and Munk. A general survey of the present status leads to the conclusion that the greatest needs at present are, first, a general experimental check on the accepted aerodynamic theory and, second, an interpretation of the theory in simple language so that it may be reduced to practice. Some work of this type has already been carried out in this country, and a fairly extensive program is laid out for the future. In particular it is considered that the work done in the variable-density wind tunnel at Langley Field offers a good opportunity of checking Doctor Munk's theories. In the matter of reducing the theory to practice Doctor Ames has recently made a very important contribution in a paper which summarizes Munk's theories and explains their application. This will be published as Technical Report No. 213.

Future study should take up the investigation of viscosity, and more especially, the study of the combination of the latter and of the unsteady motions of solids in perfect fluids. Such problems arise in connection with the analysis of the forces on airplanes in maneuvers. No adequate theoretical treatment has been made so far of the viscosity effects, and the solution appears formidable at this time. Eventually a solution may be found. In the meantime, there should be no let up either in the development of theory and its application to practice, nor in the acquisition of more empirical knowledge about viscosity. The variable density wind tunnel offers the most promising method to secure correct data for the designer which include the effect of viscosity, and a great part of such work will be carried on there.

STANFORD UNIVERSITY

During the year the following investigations have been carried to completion:

1. Loss of propulsive efficiency due to operation of air propellers forward of obstructions: This investigation has included the operation of model propellers of two different pitch ratios with three different types of obstruction, as follows:

- (a) A specially thick wing section representing the wing proposed for a new type of heavy bombing airplane.
- (b) The fuselage or mid-structural part of the same airplane as in (a).
- (c) The nose of a standard De Haviland type airplane.

For cases (a) and (b) the two propellers were run at three different values of the clearance distance, making 12 different combinations of operative conditions.

For case (c) the two propellers were run at two different values of the clearance distance and each with 3 degrees of radiator obstruction, thus making again 12 different combinations of operative conditions.

These investigations include three sets of measurements:

- I. Tests on the propellers alone.
- II. Tests on the models alone.

III. Tests on the propellers in operation in place before the models but with complete independence of suspension and control, so that all measurements may be made independently and thus give values for the propeller as influenced by the model and for the model as influenced by the propeller.

For cases (a) and (b) notable loss in propulsive efficiency was found over the normal working range of the propeller, decreasing with increase of clearance between the propeller and the airplane. There is also some evidence of a greater loss for propellers of high-pitch ratio than for low, other things being equal.

For case (c) the same general results were found, but notably smaller in amount, though still of sensible magnitude.

2. Tests of 13 Navy type model propellers: The purpose of these tests was the determination of the performance coefficients and characteristics for certain selected series of propellers of standard type and form. The first series includes 7 propellers of pitch ratio varying progressively from 0.5 to 1.1, the area, form of blade, thickness, etc., representing an arbitrary standard propeller which had shown good results. The second series covers changes in thickness of blade section, other things being equal, and the third series, changes in blade area, other things being equal. These models were all of the standard 36-inch diameter employed in this laboratory.

3. Tests of 30 model propellers of 30-inch diameter for the Army Air Service, McCook Field: These propellers are arranged in five series of six each. The first number in each series is a propeller of uniform pitch for which the pitch is progressively 0.1, 0.2, 0.3, 0.4, 0.5 the circumference. For the following numbers in each series the blade face is given a further inclination of 1, 2, 3, 4, and 5 degrees progressively. This gives two sets of series, the first with constant base ratio of pitch to circumference with angle of supplementary inclination varying from 0 to 5, inclusive, and the second with constant supplementary angle and varying base ratio. The total range of mean pitch ratio is from 0.314 to about 2.00.

4. Tests of five Navy type model propellers in connection with a model representing the mid-structural part of a Vought airplane: This investigation represents the laboratory part of a program carried on jointly with Langley Field, at which place tests with the full-scale propeller and actual airplane were carried out in the air. The laboratory tests are carried out in general manner as in investigation (1) above and show the same general character of results and with a loss in propulsive efficiency over the working range, and as compared with the propeller alone, of approximately 2 to 5 per cent.

WASHINGTON NAVY YARD

Wind tunnels.—The aerodynamical laboratory at the Washington Navy Yard is operated by the Bureau of Construction and Repair for the Bureau of Aeronautics. All technical details connected with the tests and reports are under the direction and immediate supervision of Dr. A. F. Zahm.

The equipment consists of two wind tunnels, one closed-circuit type 8 by 8 feet in cross section at the testing plane, and one open-circuit N. P. L. type 4 by 4 feet in cross section. The larger tunnel is fitted with a special six-component balance designed by Doctor Zahm and his assistants and constructed in the Washington Navy Yard. As described in N. A. C. A. Technical Report No. 146, this balance is equipped with automatic weighing beams which enable readings to be taken with great rapidity. The smaller tunnel is equipped with a modified N. P. L. type of balance also having automatic weighing beams.

The testing program is formulated for the greater part in the Bureau of Aeronautics and necessarily follows rather closely the design needs of the bureau. It is the policy, however, to make all tests as general as possible and to make available for general use all data which appear to justify publication. Such data are published from time to time as Technical Reports by the National Advisory Committee for Aeronautics, or, in special cases, by some scientific publication.

Airfoils and wings.—The work previously done on airfoil sections has been continued during the past year in tests on 19 models. No extensive research was made during the year but several unusual sections were developed. Noteworthy among these is the N-10, a modification of the Gottingen 398, which has exceptional characteristics.

Tests now under way include a series of six airfoils with various types of cut-out portions in the center of the span. The purpose of this research is to supply data in regard to the effect of cutting openings in the wing to improve vision.

Control surfaces.—An unusual amount of testing has been made on control surfaces during the past year. The most important tests were in connection with a double research on balanced controls using an auxiliary movable flap to supply the balancing moment. These tests indicated that the trailing flap balance would be successful, and arrangements have been made to carry out free flight tests on the device.

Hinge moments have been taken on the Handley-Page type of balance flap previously tested for lift and drag. The present tests complete this research. It was found that the hinge axis should be about 35 per cent of the flap chord aft of its leading edge for best results. Forty-five per cent aft gives complete overbalance.

Hinge moments were also taken for a flap located on the surface of the airfoil in order to complete a research carried over from last year.

Tests are now under way to investigate the "dead center" action of control surfaces. Six models have been constructed to give a wide range of control types.

Airplane parts.—A series of fuselage models has been constructed and is now awaiting tests. These tests are to supplement the tests on floats made last year. They are typical of Navy designs and are so selected as to give very little overlap on the Army tests.

Tests on fittings and streamline wire have been planned and the models prepared. These tests are to supply information on the resistance of certain recent types of fittings and turn-buckles. In connection with a research on streamline wire, four elliptical struts were given tests for lift and drag. Further tests are under way to study the pressure distribution on these models. The results may shed some light on the effect of changes in the cross section of streamline wire.

Complete airplane models.—During the past year routine tests have been made on 18 airplane models. The routine tests are frequently supplemented by additional tests of a research nature. As an example of this, several models were tested both as a landplane and as a seaplane, other models were tested with two or more types of tail planes, and whenever the need was considered sufficient aileron tests were included.

The accumulation of data through these routine tests forms a very desirable function of the wind tunnel. The purposes of design are not only satisfied for the present but the requirements of the future are often filled by existing test data.

Lighter-than-air.—Tests have been made for the resistance of the water recovery unit used on the *Shenandoah* under various conditions. The only other tests of this nature have been on several airship and kite balloon models supplied by private firms.

General.—An automatic speed control has been fitted to the 8 by 8 foot wind tunnel and given thorough tests. It was found to function satisfactorily.

The plane table has been fitted with additional attachments to assist in checking models. These attachments permit very rapid and accurate checks to be made on the angles and chief dimensions.

The balance in the 4 by 4 foot wind tunnel has been given a thorough overhaul and repair. It now appears to be entirely satisfactory. Check runs on the same model in the 4 by 4 foot and 8 by 8 foot tunnels are in very close agreement. The automatic balance in the 8 by 8 foot tunnel continues to give the splendid results which have characterized its operation from the beginning.

BUREAU OF STANDARDS

Wind tunnel investigations.—The aerodynamical work of the Bureau of Standards has been carried out largely with the cooperation of the engineering division of the Army Air Service, the Ordnance Department of the Army, and the National Advisory Committee for Aeronautics. The equipment available consists of three wind tunnels, one 3 feet in diameter with a speed range of 11 to 150 miles per hour, one 4½ feet in diameter with a speed range of 17 to 90 miles per hour, and one 10 feet in diameter with a speed range of 10 to 70 miles per hour.

The program of testing and research for the engineering division of the Air Service in connection with the design of the *RS-1* semirigid airship has been concluded by measurements of the pressure at 50 points on each side of the selected fin surfaces and at 36 points on each side of the selected movable surfaces for various presentations of the hull and movable surfaces to the wind. Two regions of localized high loading on the fixed surface were found, one along the leading edge and the other at the outer edge of the fin. The rudder showed a reversal of loading near the rear edge.

At the request of the engineering division, a twin hull model consisting of two hulls side by side was tested, but the drag coefficient and the unstable static moment were so large that further work was discontinued.

In cooperation with the Ordnance Department, a study has been made of the effects of systematic variations in the dimensions of flat fins, the type which has been found to be most efficient in the stabilization of aircraft bombs. The results are being analyzed in such a way as to serve as a basis for the prediction of center of pressure position. The value of increasing the breadth rather than the length has been shown.

Measurements have been made of the drag of two airship models in the 3-foot and the 10-foot tunnel in connection with the standardization program of the National Physical Laboratory. The characteristics of a standard airfoil have been measured in the 10-foot tunnel as a part of the same program.

A study of the design of trailing bombs for use in free flight research has been made for the National Advisory Committee for Aeronautics. The study included the interference effect on Pitot tubes and the design of the fins to give stability.

With cooperation of the National Advisory Committee for Aeronautics and the Ordnance Departments, measurements have been made at Lynn, Mass., of the characteristics of airfoils of the type used in propeller design at speeds approaching the speed of sound. The measurements indicate that the efficiency of a propeller of usual design will fall off rapidly as the tip speed is increased beyond the speed of sound.

Studies are in progress at Edgewood Arsenal of the behavior of air streams from orifices at speeds greater than the speed of sound. Photographs have been made of standing waves in the stream as well as measurements on model projectiles in various positions relative to the orifice. These measurements supplement the work at Lynn and serve as a guide to further measurements with larger orifices.

Work is in progress on a research for the National Advisory Committee for Aeronautics on the standardization of wind tunnel measurements and the investigation of turbulence. Studies of the measurement of variations in static pressure and speed are in progress as well as a study of the effect of scale of turbulence on cylinders.

An investigation which is not directly concerned with aeronautics but which is in the field of aerodynamics relates to the distribution of pressure over a prism with square base, the object of which is to secure information on the subject of wind pressure on tall buildings.

Aeronautic instruments section.—The aeronautic instrument section of the Bureau of Standards has continued its program of cooperative research and development work in connection with aircraft instruments with the National Advisory Committee for Aeronautics, the Navy, the Army, and other Government departments and private concerns. In addition, a considerable amount of routine testing on instruments has also been carried out.

One of the principal activities of this section during the past year has been the continuation of the development work on instruments for the United States Navy rigid airship *Shenandoah*.

A number of improvements have been made on the suspended head electric air-speed indicator used on this ship, with the result that these instruments are now giving very satisfactory service. The fabric tension meter referred to in last year's report has now been in use for nearly a year and is showing even better performance than had been anticipated. The electric resistance gas and air thermometer developed during the preceding year has been modified to give a more open scale. This instrument weighs only a quarter as much as does a German thermometer designed for the same use. An investigation of gasoline flow meters was conducted early in the year, on the basis of which a flow meter was designed at the Bureau of Standards and a number were constructed at the Washington Navy Yard for use on the *Shenandoah*. Other instruments completed for this ship include a liquid rate-of-climb indicator, an improved bubble sextant, and several special liquid and mechanical type manometers. A barograph compensated for air temperature and a camera sextant for recording sun observations are also under construction.

Instruments other than those listed above which were completed during the year for the Army and the Navy include a thermoaltigraph compensated for air temperature, a combined altimeter and barograph, an improved surveying aneroid barometer, a portable mercurial barometer, a mechanical type rate-of-climb indicator using a leather diaphragm, a horizontal angle indicator, and two static pressure type ballonet volume indicators.

Fundamental theoretical and experimental researches have been conducted in connection with the design and improvement of aeronautic instruments. These include a continuation of the investigation of instrument diaphragms, both metallic and nonmetallic, a study of the characteristics of pressure elements, an investigation of instrument mechanisms together with an analysis of a simple toggle arm motion for use in altimeters, an extensive experimental investigation of the friction of a number of types of small instrument bearings, and an investigation of helical springs for use in pressure elements. These various researches have three objects in view: (1) The simplification, improvement, and standardization of instrument mechanisms, (2) the improvement of instrument pressure elements, and (3) the obtaining of performance data for various types of pressure elements, bearings, and mechanisms for use in design, and the dissemination of this information.

An increasingly important feature of the work of this section is the calibration of barographs carried in flights made for the purpose of breaking altitude records and the determination of the maximum altitude attained during the flight. During the past year the barographs were calibrated by subjecting them to flight-history tests, i. e., tests in which the instruments are subjected to the same pressure and temperatures and to the same rates of change of these quantities as were encountered during the flight. In this way the temperature and elastic errors of the instruments are almost entirely eliminated and an accurate determination of the ceiling pressure is made possible. When this pressure has been determined, it is converted to altitude by means of the altitude-pressure relation specified by the Federation Aeronautique Internationale. These altitude determinations are made for all flights in the United States for which a statement of the altitude attained is submitted to the Federation Aeronautique Internationale for homologation. Fourteen such altitude determinations were made at the Bureau of Standards during the past year from flight-history tests run on 21 barographs.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Wind tunnels and instrumental equipment.—The two wind tunnels, one 4 feet and the other 7½ feet in diameter, have continued in use throughout the year, the larger tunnel being used almost entirely for research work, while the smaller serves the purposes of instruction and is employed also in commercial testing and in thesis investigation by the aeronautical students. No changes have been made in the tunnels themselves.

A new wire balance has been constructed for the special purpose of determining rolling and yawing moments. A propeller dynamometer, designed for use in testing propellers in the presence of complete models in the large wind tunnel, has also been completed and undergone

preliminary tests. It furnishes the power necessary to run a one-quarter scale model of a Liberty engine propeller at 5,000 r. p. m.

Airfoil tests.—The work on a standard series of airfoils initiated during the previous year has been continued to completion. About 25 sections, including those which appear best from all laboratories, have been tested under identical conditions, and those which seemed most promising in the first test were run at a number of different speeds. This work affords strictly comparable data for the best airfoils originated in Europe, as well as for those of American design.

Model tests.—The practice of testing complete models for the Army Air Service has been continued, and a large quantity of information on control and stability characteristics has been obtained. Special attention has been given to the determination of rolling and yawing moment due to ailerons, both on complete models and on standard airfoils fitted with ailerons of varying spans and chord.

Miscellaneous.—In addition to numerous tests of airplane and airship parts of variable lift wings, etc., several aerodynamic investigations outside the strict field of aeronautics have been carried out in the wind tunnels. An extended study of the aerodynamics of yacht sails has been made, with the object of determining the best form and curvature for a sail, and a series of tests on the pressure distribution over buildings and structures of various sorts has recently been initiated.

McCOOK FIELD

General.—The McCook Field wind tunnel equipment comprises a 5-foot, 1,000-h. p., 260 m. p. h. tunnel, and a 14-inch, 200-h. p., 500 m. p. h. tunnel. During the year the latter has not been in much use due to its being moved into the large wind tunnel building and also due to lack of sufficient personnel to carry on the various tests for which it is suited.

The large tunnel has been in continuous use, handling 150 tests at speeds up to 250 m. p. h. Of this number 17 were airfoil, 24 model, and 15 fuselage tests.

Air flow examination.—Tests were made for determining the proportions of the straightener to be used in the 5-foot wind tunnel as a substitute for the temporary honeycomb installed in 1922. These tests were a continuation of air flow studies made in connection with the 14-inch wind tunnel design in 1918; the construction of the proper apparatus will be shortly completed.

Precision manometer.—A new 10-inch precision manometer of the Whalen type has been put into operation. The gauge is connected direct to the wind tunnel and records pressure changes of 0.03 per cent at the top of its range.

Determination of hinge moment.—A study was made for determining small moments on a stabilizer-elevator tail combination.

Trailing edge flap.—A model DH-4B was equipped with trailing edge flaps and tested for lift, drag, and moment.

Shift of burble point on multiplanes.—Further tests were run on multiplane combinations in which the increase of critical angle in multiplanes was shown.

Tail surfaces.—Tail surface-elevator combinations, three of differing plan-form, three of differing hinge-location, were tested for lift, drag, and moment at various angles.

Wing vibration.—A preliminary rough examination was made of the aerodynamic characteristics connected with wing flutter accidents in full-size airplanes. Only an introduction was made to the problem, but preliminary conclusions were formed that the mechanics of the flutter phenomena were more important than the aerodynamics in determining this danger in aircraft.

TP-1-CO-5 series of tests.—Measurements of energy gradients in air flow in region of tail of this model were made, using Pitot tube method developed in 1910. The purpose was to investigate causes of poor directional control noticed on a full-scale airplane during the moment of take-off.

The effect of the proximity of the ground on the yawing control of this model was also investigated by introducing dummy ground planes in the tunnel, and the results were tabulated showing change of lift and drag for these conditions.

Tests of general interest.—In a few cases during the year 1923-24 the speed capabilities of the 5-foot tunnel have been used. It has been found profitable to incorporate in routine work

"speed tests" of the minimum drag of models at angles of small lift up to a speed limited only by the strength of the models. The highest speed actually used in routine tests has been 250 m. p. h. on a small fuselage model.

The series of high-speed propeller airfoil tests, commenced in the 14-inch wind tunnel in 1921, are to be continued and extended.

Heat transfer.—A full-size 8½-inch wide section of a Curtiss wing radiator with 68-inch chord was tested for the purpose of checking up its cooling capabilities with flight performance. While the airfoil in which this section was mounted was full size and the tunnel wall effect therefore greatly exaggerated, the results obtained were thought to be consistent with the usual accuracy of radiation tests. At any rate, the exponent of "V" was found to check the 1921 tests made in the 14-inch wind tunnel on typical radiation surfaces; the B. t. u. transfer was shown to be greater than is always obtained in flight, with the conclusion that in certain full-size airplanes there are conditions such as air pockets which lessen the proper performance of this type of radiator.

Resistance of air-cooled cylinder heads.—Two actual air-cooled cylinders were tested for the purpose of investigating the change of resistance due to housing the valve rockers. The method of support was by fine wire suspension, the main body of the cylinders being protected from the air stream by large streamline shields, so that only comparative results for the two cylinders tested were obtained.

Officers' school instruction.—In connection with the officers' training school course at McCook Field, a period of wind tunnel testing is included for various groups. In the present year one period of approximately 10 days was devoted to this purpose, the officers taking part in the wind tunnel operations and in the calculations of typical tests on airfoils and models.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

ORGANIZATION

The committee on power plants for aircraft is at present composed of the following members:

Dr. S. W. Stratton, Massachusetts Institute of Technology, chairman.
G. W. Lewis, National Advisory Committee for Aeronautics, vice chairman.
Henry M. Crane, Society of Automotive Engineers.
Prof. Harvey N. Davis, Harvard University.
Dr. H. C. Dickinson, Bureau of Standards.
Leigh M. Griffith, Langley Memorial Aeronautical Laboratory.
Edward T. Jones, engineering division, McCook Field.
Lieut. Commander E. E. Wilson, United States Navy.

FUNCTIONS

The functions of the committee on power plants for aircraft are as follows:

1. To determine which problems in the field of aeronautic power-plant research are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding aeronautic power-plant research in progress or proposed.
4. To direct and conduct research on aeronautic power-plant problems in such laboratories as may be placed either in whole or in part under its direction.
5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

By reason of the representation of the Army, the Navy, the Bureau of Standards, and the industry upon this subcommittee it is possible to maintain close contact with the research work being carried on in this country and to exert an influence toward the expenditure of energy on those problems whose solution appears to be of the greatest importance, as well as to avoid waste of effort due to unnecessary duplication of research.

The committee on power plants for aircraft has direct control of the power plants research conducted at Langley Field and also of special investigations authorized by the committee and conducted at the Bureau of Standards. Other power-plant investigations undertaken by the Army Air Service of the Bureau of Aeronautics are reported upon at the meetings of the committee of power plants for aircraft.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

FUEL INJECTION ENGINE—*Spray photography.*—The apparatus for taking high-speed series photographs of sprays produced by fuel injection valves has been further developed. Certain fundamental changes have served to eliminate a number of weaknesses, so that much more satisfactory results have been obtained. With this apparatus the illumination is provided by the discharge of a condenser across a spark gap, which condenser is itself charged by a number of high-voltage storage condensers. The character of the electrical connections determines the rate of charge of the discharge condenser and therefore the timing of successive pictures of a series. Inductance coils which had been used to control the charge rate have been replaced by a series gap and an inductance of comparatively great resistance. The inductive resistance acts to limit the flow of energy, while the spark gap, through its tendency to interrupt the current after it reaches a certain minimum value, serves to disconnect the discharge condenser from the storage condenser. High-voltage alternating current is rectified by a series of kenotrons for charging the storage condensers, the peak of the alternating current wave being utilized for obtaining the maximum flow of energy by proper timing of the start of a series of pictures. The ionization of the air at the main spark gap reduced the voltage required for successive discharges, so that poor distribution of pictures was obtained. This difficulty was overcome by a blast of CO_2 gas through the spark gap.

Pictures have been taken which show the development of the spray when using a 0.015-inch orifice and a positively operated injection valve. The valve discharges into a chamber filled with nitrogen, which prevents combustion and approaches actual engine conditions. Nitrogen pressures up to 300 lb./sq. in. and fuel pressures up to 6,000 lb./sq. in. were used, so that the effect of both fuel pressure and back pressure upon spray tip velocity and dispersion are estimated.

Pumps and valves.—The further study of this phase of the fuel injection engine problem, led to the construction of a special eccentric operated high pressure injection pump controlled by means of the suction valve. This pump, in connection with a number of diaphragm injection valves, has been studied by means of special bench apparatus for determining the relative timing of events. This work, combined with actual engine tests with the same fuel injection system, will enable a logical study of the elements of control.

The study of the load-deflection characteristics of diaphragms suitable for use in injection valves has shown that the usual theoretical formulas can be applied only when the deflection is exceedingly small in relation to the unsupported diameter. The practical application of diaphragms in injection valves involves deflections far in excess of this limiting value, and this work has given valuable information for the application of diaphragms to injection valves.

The discharge characteristics of a refined cam-operated pump especially adapted for high speed operation and controlled by changing the pump stroke has been studied while discharging into free air.

Fuel injection engine test work.—Efforts on actual engine work have been concentrated for the most part on the study of the application of fuel injection to the two-cycle engine with spark ignition. A modified Liberty engine cylinder mounted on a single-cylinder engine base was used for this purpose. The tests included injection direct into the combustion chamber from a number of different cylinder locations and into the air stream at the entrance into the cylinder. While operation at light loads and low speeds has not been satisfactory, high capacity has been secured. With external injection 51 b. h. p. was obtained at 1,400 r. p. m. giving a brake mean effective pressure of 103 lb./sq. in., while, with internal injection, slightly over 80 lb./sq. in. was obtained. The corresponding scavenging pressures are under $5\frac{1}{2}$ lb./sq. in. About 30 b. h. p.

per cylinder is obtained with the standard Liberty engine at the same speed. No further compression-ignition work has been done, because the engine equipment was needed for other work.

Fuel characteristics.—The vapor pressure-temperature relations of Diesel engine oil, wood and ethyl alcohol, kerosene, gasoline, and benzol have been determined. This work was carried out by heating a certain quantity of fuel in an air-tight steel container to about 1,000° F. and noting the pressures obtained. In case of several of these fuels, considerable pressure remained after complete cooling and the remaining liquid was materially different from that put in. The temperatures and pressures recorded gave further indications of important chemical reactions at the higher temperatures, during both heating and cooling.

Determinations have been made of the coefficients of discharge of a number of orifices such as would be used in simple fuel injection valves. Values have been established for discharge under hydraulic pressures up to 8,000 lb./sq. in. and at varying temperatures into air at pressures up to 1,000 lb./sq. in., using Diesel fuel oil, gasoline, and water. When discharging into air at atmospheric pressure, the coefficient was found to be practically constant above 1,000 lb./sq. in. fuel pressure, varying between 0.62 and 0.75 for the various orifice sizes and fuels tested. A critical pressure relation was noted in discharging into compressed air. For any given hydraulic pressure there was a certain back pressure below which the coefficient remained practically constant, but above which it decreased rapidly as the air pressure approached the hydraulic pressure. In these tests the critical air pressure was found to be 0.3 of the hydraulic pressure.

Supercharging—Roots type.—Flight study of this supercharger involving work at high altitudes with DH-4 and DT-2 airplanes has been continued and the gain in performance due to supercharging established. Supercharging increased the practical ceiling of the DH-4 from 14,500 feet to 31,000 feet and of the DT-2 from 18,500 feet to 28,000 feet. In the case of the DT-2, supercharging reduced the time required to reach an altitude of 18,000 feet from 59 minutes to 33 minutes.

This type of supercharger has been applied to a service seaplane with a considerable gain in performance. In this work, loaded conditions have been given particular attention. With a gross load of 7,380 pounds (useful load of 1,500 pounds), the unsupercharged seaplane has very nearly reached its ceiling after a climb of 6,300 feet in one hour. With the same useful load, an altitude of 8,000 feet was reached in the same time by supercharging with but little decrease in the initial rate of climb.

A new design of this type of supercharger has been completed that includes modifications as found desirable from experience with the present machine. Provisions have been made also for a material increase in speed of operation.

Supercharging air-cooled engine.—In view of the increasing need for supercharging service engines, and the present importance of air-cooled engines, an investigation of the effect of supercharging upon air-cooled engine performance has been undertaken. For this purpose, a Roots type supercharger was adapted for use with a Lawrance J-1 engine installed in a TS airplane. Preliminary tests have been completed in which a material improvement in airplane performance was obtained without impairing the engine. An automatic observer was used to obtain complete records during the flights. Some cylinder temperatures were included in the observations, giving at 16,000 feet a cylinder temperature of 360° F. unsupercharged and 500° F. when supercharged to a carburetor pressure of 28" Hg. The maximum temperatures recorded were 420° F. and 510° F., respectively for the two conditions. With respect to airplane performance, a climb to 16,000 feet in 45 minutes was increased to 25,000 feet in the same time by supercharging.

Other supercharging problems.—In connection with the general supercharger work, it became desirable to determine the effect upon power of air charge temperatures much in excess of those investigated in previous work. Tests to determine this relation have consequently been started with two types of modern service engines.

The relative performance of a normal aircraft engine, a supercharged normal-compression engine, an overcharged and supercharged low-compression engine and an overcompressed and

overdimensioned engine is being further investigated. A series of tests have been made with the universal test engine to establish more definitely the loss in power encountered by throttling a very high compression engine at the ground level so that ordinary domestic aviation gasoline can be used without encountering serious detonation. Incidental to certain phases of this work, investigations have been made with a number of dopes for suppressing detonation. This general problem will be further investigated during the present year, both in flight and in the laboratory.

Power plant laboratory equipment.—Considerable study has been made of laboratory methods of measuring air consumption of engines. While it appears clear that pulsation effects of single-cylinder test engines can be controlled to an extent where no harmful effects are imposed, it is believed that the gasometer is the most reliable means that lends itself conveniently to work of this kind at the present time. Consequently a gasometer installation is being made.

Separate small synchronous motor generators are being installed to maintain a constant excitation voltage on the dynamometers for the nicer test work.

The subject of engine indicators has been given consideration and a modern type of indicator altered to increase its utility.

BUREAU OF STANDARDS

Changes in engine performance resulting from changes in compression ratio.—This investigation has been based primarily upon tests of aviation engines in the altitude laboratory, though a single-cylinder engine has been employed for certain phases of this work. The report shows an increase in power and a decrease in specific fuel consumption to result from an increase in compression ratio provided no serious detonation or preignition occurs. Compression ratios up to 14 to 1 were investigated.

Effect of fuel-air ratio on engine performance.—The report is based upon the work of several years and deals primarily with the performance of aviation engines. In the report it is shown that maximum power is obtained with approximately the same fuel-air ratio over the range of air pressures and temperatures encountered in flight and that nearly minimum specific fuel consumption is obtained by decreasing the fuel content of the charge until the power is 95 per cent of its maximum value.

Performance of Curtis D-12 engine.—This engine was tested in the altitude laboratory and a report submitted to the Bureau of Aeronautics of the Navy Department. The program of tests authorized by this bureau is of so broad scope that when an engine has been tested in accordance with it one may predict with fair accuracy the performance of the engine under any normal condition of operation at any altitude. The performance of the engine was excellent from the standpoint of volumetric efficiency, mean effective pressure, and freedom of vibration.

Supercharging of aircraft engines.—A few tests have been made of the performance of the D-12 engine under supercharging conditions. For the most part the work of the present year has been confined to the preparation of apparatus and instruments.

Ignition systems.—A detailed study has been made of the performances of a group of typical automotive ignition systems. The objects of this work are (1) to find the performance which usually may be expected of the ignition apparatus now on the market; (2) to test the correctness of the theories of such apparatus as published in the literature, when applied to different types of systems; (3) to correlate design and performance and thus aid the manufacturer in improving his designs; and (4) to devise simple tests requiring only inexpensive apparatus so that the small manufacturers or the purchaser of ignition equipment may obtain at least a rough idea of its performance.

Phenomena of combustion.—This work is primarily an investigation of factors of fundamental importance as regards the rates of explosive gaseous reactions with a view to obtaining a better knowledge of these reactions under the conditions imposed by internal-combustion engines. The use of the soap bubble as a constant pressure bomb has proved of great value in the study of these reactions. Apparatus has been constructed which will permit the soap bubble

to be used as a constant pressure bomb at pressures other than atmospheric. This will permit a study of the effect of pressure upon the reaction and flame velocity.

Fuels for high-compression engines.—A report covering several years' work on this subject has been prepared for publication by the National Advisory Committee for Aeronautics. It is now in the hands of the editorial committee of the power plants section of the bureau. It deals with the requisite properties of a fuel for high-compression engines and comments at length upon the phenomena of preignition and detonation. The performance characteristics of alcohol and benzol and blends of each with gasoline are discussed in some detail.

Dew points of fuel-air mixtures.—Apparatus for determining the minimum temperature necessary to keep a mixture of fuel and air completely vaporized has been developed and its description is to be published in one of the bureaus' scientific papers. The theory of the method rests on the assumption that the initial condensate in equilibrium with the remaining vapor is of essentially constant composition for the range of pressures and temperatures encountered in the engine manifold.

Fuel atomization in carburetors.—This investigation has dealt with the fundamental factors influencing drop size and the transportation of liquid fuel from the carburetor to the engine. One such factor is discussed in a paper on the "Effect of the Degree of Instability on the Phenomena of Round Liquid Jets" which has been prepared for publication.

Distribution of fuel versus engine performance.—Measurements of the power and specific fuel consumption of a single-cylinder engine were used as a basis for calculating the effect of certain inequalities of distribution upon the performance of a multicylinder engine.

Engine tests of lubricants.—A test procedure has been developed which seems satisfactory for the comparison of oils on the basis of their stability and the rate at which carbon is formed. These tests show, as did previous ones, that the rate of carbon formation is dependent upon the temperature of the combustion-chamber walls. The minimum rate of carbon formation appears to be obtained when the fuel-air ratio is that giving maximum power.

Development of oxidation test for routine testing of mineral oils.—The stability, resistance to oxidation, of mineral oils appears to be one of the factors which determine the life of such oils in service. The oxidation test developed at the bureau subjects the oil for two and one-half hours to a temperature of 200° C. in an atmosphere of oxygen. With the method as now used excellent reproducibility is obtained.

Standardization of viscometers.—Two viscometers, the Saybolt Universal for lubricating oils and the Saybolt Furol for fuel oils, are standard for testing petroleum products. The accuracy of standardization of these instruments has been increased, and the standard made more permanent by the adoption of master tubes kept at the Bureau of Standards. These tubes have been approved by the appropriate committees of the American Petroleum Institute and the American Society for Testing Materials. Considerable work has been done in cooperation with these societies in standardizing the constant temperature bath and method of test.

Investigation of bearing friction.—This work has consisted primarily of experiments with a view to the obtaining of consistent and reproducible results with the journal friction machine employed. A very fair measure of success has been attained, repeat curves showing quite satisfactory agreement.

Fluidity of oils at low temperatures.—This investigation has consisted in the development of a laboratory instrument to give an arbitrary measure of the tendency of an oil to flow at low temperatures and in the use of the instrument on testing oils. The investigation has shown that the present pour test fails as a measure of the tendency of an oil to flow at the low temperatures sometimes encountered in the operation of an airplane engine, as under these conditions a paraffin base oil shows a more rapid rate of flow than a naphthene oil of much lower pour test.

Airplane radiators.—Measurements in flight have been made of the air flow through radiators mounted in various positions on a Vought seaplane. The method employed was first to determine the relation between air flow and heat dissipation for the radiator in the laboratory and then to determine the air flow in flight by measurements of heat dissipation. A hot wire

integrating anemometer was designed and used as an independent means of measuring air flow through a radiator in flight.

Wind tunnel measurements of air flow through radiator cores have been made at air speeds of from 50 to 140 miles per hour. For laboratory measurements of air flow through radiator cores, the hot wire integrating anemometer and a specially calibrated small Pitot tube have proved superior to instruments previously used for this purpose.

A critical analysis has been made of the conditions governing the use of a Pitot tube to measure air velocity in a small tube like a radiator cell. The analysis shows that four corrections must be applied to the Pitot reading, these being due to (1) the acceleration of air at the forward end of the Pitot tube, (2) the pressure drop along the cell between the dynamic and static openings, (3) the effect due to a partial obstruction of a cell by the Pitot tube, and (4) the velocity distribution across the cell.

NEW ENGINE TYPES

Most of the energies of both the Bureau of Aeronautics of the Navy Department and the engineering division of the Army Air Service have been directed toward the improvement of existing types of engines with particular attention to accessories. The Bureau of Aeronautics and the Air Service are in close cooperation in their developments and steps have been taken to standardize engines, accessory drives, and accessories. A few new engine types have been experimented with, however. The Air Service is developing and testing two radically different engines. One of these is known as the cam engine and the other the barrel type or Almen engine. The Bureau of Aeronautics has let a contract for an experimental heavy oil engine with a view to further development of such an engine for use in lighter-than-air craft.

The Navy's heavy oil engine is being constructed by the Eastern Engineering Co. (Ltd.), of Montreal. It is a two-cylinder, two-stroke cycle, auto-ignition, solid injection engine of 125 h. p. at 1,800 r. p. m. At its rated power it is required to have a specific fuel consumption of 0.50 and to weigh not more than 3.8 pounds per horsepower. The engine is a conventional engine in every way and since a somewhat similar engine, as applied in automobile demonstrated excellent flexibility, it is hoped that considerable advance may be had in the development of this engine.

The Wright model "J" engine has advanced to the model J-4 type. The J-3 engine was quite similar to the original Lawrance J-1. Fifty of these engines have been delivered to the Navy. A contract has been let by the Navy for 155 of the model J-4 engines and this engine will differ from the J-3 principally in the fact that the steel cylinder sleeve has been flanged for bolting to the crank case, thus replacing the aluminum flange of the model J-3. Considerable improvement has been made in the cooling arrangements on the model J-4 cylinder. The valve seats are to be inserted and rolled in rather than cast in as in the J-3, and some changes have been made in the cylinder head to eliminate hot spots. As a result, the model J-4 engine on test has developed about 10 per cent greater horsepower than the J-3 at the same crank shaft speed and has shown itself capable of running at 2,000 revolutions. The model J-4 engine has now run over 100 hours on a type test and has shown excellent durability. Model J-1 engines in service have shown over 150 hours of reliable operation between periods of major overhaul. It is therefore anticipated that the J-4 engine will be capable of prolonged periods of operation without major overhaul.

As a concrete example of the comparative performances of the air and water cooled engines, it has been shown that the Navy's VE-7 fighter equipped with a Wright 200 h. p. water-cooled engine and flown as a single seater has exactly the same performance as the model UO-1 airplane flown as a two-seater observation airplane with radio and utilizing the Wright 200 h. p. air-cooled engine. The difference, then, between air-cooled and water-cooled engines in the same type of aircraft is the difference between one seat and two seats plus radio.

As a development of the air-cooled engine, the Navy is contemplating the investigation of the Moss type supercharger gear-driven. This supercharger has been developed by the Air Service at McCook Field. It is proposed to utilize the supercharger for observation air-

planes primarily for rotary induction and improved distribution. By a change in the gearing, it is proposed to supercharge to higher altitudes for fighters. By running the engine at higher speeds in fighters, it may be possible to utilize the Wright 200 h. p. engine on shipboard airplanes for both observations and fighters. This is a most desirable solution for the reason that shipboard airplanes must be of small size and weight and it is highly desirable to power them with the same engine in order to reduce the maintenance problem.

Both the Air Service and the Bureau of Aeronautics are purchasing a few of the new Packard 1A-1500 and 1A-2500 engines. These orders are development orders and the engines are intended for installation in aircraft for flight testing in order to bring out any possible defects prior to the letting of production orders. The Air Service and the Bureau of Aeronautics have cooperated in the specifications for these engines in order that they may be made standard to both services. The model 1A-1500 is a 400-500 h. p. water-cooled engine of extremely low weight per horsepower. The model 1A-2500 engine is a 700-800 h. p. engine of similarly light weight. These engines incorporate many new features, such as improved light cylinder construction, twin exhaust valves and twin inlet valves operated by one cam shaft, dual Splitdorf magneto, combined fuel and lubricating pump arrangements with a single drive, and distributors located inside the V. Some of the engines will be equipped with gears having a ratio of 2 to 1, while others will be flown in the normal vertical position and others inverted.

The Curtiss D-12 engine has continued to give excellent results in pursuit type airplanes. The Air Service has promoted the development of a new steel-backed babbitt bearing at the plant of the Allison Engineering Co. These bearings on test have shown greatly improved performance due to the rigidity of the bearing shells. These bearings in the Curtiss D-12 engine have given excellent service results and their adoption by both the Navy and Army is probable.

The Navy has purchased 100 Wright T-3 engines for installation in a new combined scout-torpedo-bombing airplane. These engines in service have shown themselves to be highly dependable. In service they are operating from 250 to 300 hours between periods of major overhaul. One of these engines in an SDW-1 seaplane has recently broken the world's seaplane endurance record by remaining in the air 20 hours and 18 minutes. At the end of the flight the engine was still in excellent condition, the flight being terminated when the gasoline supply was expended. These engines have also been flown at 6 to 1 and $6\frac{1}{2}$ to 1 compression ratio and have given excellent results.

Both the Air Service and the Bureau of Aeronautics are developing air-cooled engines of approximately 400 h. p. The Air Service development is being handled by the Curtiss Aeroplane and Motor Corporation. The engine has been delivered and has shown excellent promise on its preliminary tests. It is of 1,454 cubic inch capacity and is equipped with a Moss type supercharger capable of supercharging to sea level conditions at 7,500 feet and used partly as a rotary induction system. This engine weighs in the neighborhood of 727 pounds and is a very smooth running engine. At the plant of the Wright Aeronautical Corporation, the Navy is now testing its new model P-1 engine. This, like the Curtiss radial, is an air-cooled static radial. It has a displacement of 1,650 cubic inches and weighs about 800 pounds. At the present writing it has completed 30 hours of its 50-hour type test and appears a promising development.

The development of aircraft engines by the two services has been a steady, rational one, with the result that highly dependable engines are now available in every power from 150 to 800. The Wright model "E" is a 200 h. p. engine. The Curtiss 5 D-12 is a 300-400 h. p. engine. The Packard 1A-1500 is a 400-500 h. p. engine. The Wright T-3 is a 500-600 h. p. engine and the Packard 1A-2500 is a 600-800 h. p. engine.

Attention has been devoted in both services to the improvement of engine accessories. It is hoped that greatly improved ignition equipment will be available in a period of a few months. The Air Service has developed a flexible drive for fuel pumps and this is being adopted

by both the Bureau of Aeronautics and the Air Service wherever the gas tank location renders it desirable. This fuel pump will eliminate all air pressure fuel systems in the near future.

The Aeromarine Plane & Motor Co. has developed a new type starter for the Navy. In this starter, the inertia of a small flywheel is utilized to crank the engine on starting. The starter is very light in weight and has shown very excellent performance, particularly with large engines.

In general, the Bureau of Aeronautics and the Air Service are cooperating very closely in engine development and this development is taking the form of greatly improved performance of engines which have demonstrated their air worthiness.

REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT

ORGANIZATION

Following is a statement of the organization and functions of the committee on materials for aircraft:

Dr. G. K. Burgess, Bureau of Standards, chairman.
 Dr. H. L. Whittemore, Bureau of Standards, vice chairman.
 S. K. Colby, American Magnesium Corporation.
 Henry A. Gardner, Institute of Industrial Research.
 Prof. George B. Haven, Massachusetts Institute of Technology.
 Zay Jeffries, Aluminum Co. of America.
 J. B. Johnson, engineering division, McCook Field.
 G. W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
 Commander H. C. Richardson, United States Navy.
 Prof. Edward P. Warner, Massachusetts Institute of Technology.
 Dr. Carlile P. Winslow, Forest Service.

FUNCTIONS

1. To aid in determining the problems relating to materials for aircraft to be solved experimentally by governmental and private agencies.
2. To endeavor to coordinate, by counsel and suggestion, the research and experimental work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding investigations of materials for aircraft, in progress or proposed.
4. The committee may direct and conduct research and experiment on materials for aircraft in such laboratory or laboratories, either in whole or in part, as may be placed under its direction.
5. The committee shall meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on materials for aircraft, through its personnel acting as a medium for the interchange of information regarding investigations on materials for aircraft, is enabled to keep in close touch with research in this field of aircraft development.

Much of the research, especially in the development of light alloys, must necessarily be conducted by the industries interested in the particular development and both the Aluminum Co. of America and the American Magnesium Corporation are represented on the committee. In order to cover effectively the large and varied field of research on materials for aircraft, three subcommittees were formed, as follows:

Subcommittee on metals (Dr. G. K. Burgess, chairman).
 Subcommittee on woods and glues (Prof. H. L. Whittemore, chairman).
 Subcommittee on coverings, dopes, and protective coatings (Henry A. Gardner, chairman).

Most of the research in connection with the development of materials for aircraft is financed directly by the Bureau of Aeronautics of the Navy Department and the engineering division of the Army Air Service.

The Bureau of Aeronautics and the engineering division of the Army Air Service in connection with the operation of tests in their own laboratories apportion and finance research problems on materials for aircraft to the Bureau of Standards, the Institute of Industrial Research, and the Forest Products Laboratory.

At the beginning of the fiscal year the chairman of the committee on materials for aircraft requested suggestions as to research on aircraft materials from members of the committee and others. The suggestions received can be divided into three groups: (a) Aircraft materials now used and not produced in the United States; (b) new aircraft materials; (c) improved processes used in fabrication, inspection, and protection. The work of the committee during the past year has been largely influenced by the suggestions received.

The necessity of uniform specifications for aircraft material, particularly for governmental service, and standards of size and shape for parts of aircraft were brought to the attention of the committee. The committee decided that problems of this nature should come under the activities of the Federal Specifications Board.

Under the subject of aircraft materials not produced in the United States particular attention was given to a substitute for parachute silk, and at the request of the committee funds were provided for this investigation.

At the request of the committee funds were also provided for initiating the investigation of fatigue tests at high speed. If possible, a high-speed fatigue-testing machine embodying entirely new principles will be designed to give from 20,000 to 40,000 repetitions of stresses per minute. This is one of the most difficult problems in the experimental measurement of the properties of materials.

SUBCOMMITTEE ON METALS

Flexural fatigue tests.—The duralumin girders which form the framework of the *Shenandoah* will not fail by "fatigue" in less than 40 years under service conditions. This has been shown conclusively by the investigation, during the past three years, of the properties of duralumin and steel, which was made at the Bureau of Standards for the Bureau of Aeronautics, Navy Department. It is probably the most extensive investigation of the properties of sheet metal which has been undertaken in this country.

There were nine tests for both the steel and the duralumin, of which the first five are often used—(1) tensile, (2) hardness (Brinell, Rockwell, and Scleroscope), (3) Erichsen cupping test, (4) chemical analysis, and (5) microscopic examination.

To measure the resistance of sheet duralumin to loads which may come on aircraft, including abuse, tests were devised which required new apparatus. These were—(6) reverse bending about rollers, (7) tensile impact, (8) repeated impact, and (9) a flexural fatigue test.

The flexural fatigue resistance of thin sheet metal has been measured for the first time in this investigation. Some of the duralumin specimens withstood 200,000,000 cycles of stress.

Mooring spindle of U. S. S. "Shenandoah."—On the night of January 16, 1924, the airship *Shenandoah* was subjected to a strength test of an entirely unforeseen character when the airship broke away from its moorings mast at Lakehurst. The airship was subject to winds of extremely high velocity, approximating 75 miles per hour. The failure of a portion of the outer cover of the top vertical fin which lodged on the top vertical rudder subjected the ship to very violent lateral and rolling forces. The load upon the bow mooring spindle became so great that it deflected and jammed in its bearings. This caused the torsional effects of the rolling of the ship to be carried by the girders in the bow structure. As a result the structure supporting the bow mooring spindle was torn out of the ship. At the request of the Bureau of Aeronautics, Navy Department, the Bureau of Standards made tests on the bent mooring spindle to determine the wind forces to which the *Shenandoah* was subjected.

Although the forces which produced a permanent deformation in the structure can not, in general, be determined with accuracy, an approximate method of examination and analysis was developed, applicable in the case of a ductile material to any axially symmetrical deformed structure.

The data needed for such an estimate are the extent of the observed deformation and either the residual stresses or the forces necessary to restore the form of the structure. The latter method was used in this case.

To obtain the permanent deformation the spindle was mounted in a lathe and by means of micrometers maximum and minimum distances that the spindle was "off center" were determined for various stations along its length.

The curvature of the axis was found by what was, in effect, a double differentiation of observed data. First and second differences were computed from the observed "off-center" readings. These in turn were "smoothed," giving a curve which represented the observed readings.

The second differences represented, then the approximate curvature of the spindle at each station, and though subject to large errors it is believed that they do not appreciably affect the location of the maximum curvature, which would also be the location of maximum stress.

The law of plastic flow above the yield point of the material was assumed to take place at a rate roughly proportional to the excess of stress above that point. It was also assumed that the load, under which the spindle was bent, was applied suddenly, as with a sudden jerk and also that the reactions occurred at the bearings through which the spindle was attached to the ship.

Based on the above assumptions and by the use of a simple theory a moment distribution was found which gave a fair representation of the load distribution which bent the spindle.

The spindle was then placed in a testing machine and the calculated moment distribution duplicated. The load was first applied in the same direction as the original wind load to secure an estimate of the range of elastic deformation as free as possible from the previous deformation. At a load of 17,000 pounds, corresponding to a reaction of 9,880 pounds at the mooring attachment, a further permanent deflection of 0.003 inch was observed. A wind load of 10,000 pounds would therefore have produced a small permanent deflection in the spindle. The corresponding extreme fiber stress is 28,300 pounds per square inch. The material evidently met the specification requirements of 28,000 to 36,000 pounds per square inch yield point.

The spindle was then turned over and approximately straightened under steady load. Permanent deflection became noticeable at a load of 8,000 pounds (showing the effect of previous overstressing in the opposite direction) and increasing rapidly with the load. The loading was carried to 23,100 pounds, corresponding to a reaction of 13,400 pounds at the mooring attachment and an extreme fiber stress of 38,400 pounds per square inch.

The spindle was again mounted in the lathe and off-center distances obtained as before. The amount that the spindle had been straightened was obtained.

Analysis showed that the difference between the original bending and the straightening was of the kind to be expected from the difference between a suddenly applied and a slowly applied load.

It was found that the material of the spindle evidently met specification requirements for yield point; that the axis of the spindle bent elastically approximately 0.14 inch out of line for each 10,000 pounds of load applied at the mooring attachment; and that the load was certainly greater than 13,400 pounds, the steady load that produced the straightening in the testing machine; and probably greater than the 27,000 pounds estimate by the rough theory.

The Bureau of Standards also examined specimens from fractured duralumin girders of the U. S. S. *Shenandoah*. The fractures were compared with fractures obtained from tensile, tensile impact, repeated bend, and fatigue tests. The fractures in the specimen from the *Shenandoah* were found to be of the type characteristic of tensile or tensile impact. None of the broken pieces showed any evidence of a fatigue failure. This was confirmed by a microscopic examination.

Tests have also been made on an S. K. F. self-aligning roller bearing, a duplicate of the one now used on the U. S. S. *Shenandoah*, for the Bureau of Aeronautics, Navy Department.

This bearing was subjected to loads greater than those which would occur in service. No evidence, however, of permanent deformation was found from these tests.

Strength tests of airplane bolts.—Airplane fittings are usually bolted to the wing spars or other member. Sometimes the load on the fitting causes a tensile stress in the bolts, but more often it is a combination of tensile and shearing stresses because the load is not parallel to the axis of the bolt.

To measure the strength of bolts for the conditions under which they are used, the Bureau of Standards, at the request of the Bureau of Aeronautics, Navy Department, designed and built a fixture for holding airplane fittings at various angles in a testing machine. The strength of the bolts, when failure occurred, was measured by the beam reading. It was found that—

1. If the bolt was put through the member so that the head came in contact with the fitting, the strength was greater than if the nut came in contact with the fitting.

3. The strength of the bolt increased with an increase in the angle between the axis of the bolt and the direction of pull. This increase was greater for the bolts of large diameter than for those of small diameter.

SUBCOMMITTEE ON COVERINGS, DOPES, AND PROTECTIVE COATINGS

During the past year, at the Henry A. Gardner laboratory in Washington, extensive investigations have been carried on for the Navy Department in the development of fabrics, dopes, and protective coatings. The work that has been conducted for several years on the development of suitable fabrics for gas cells for rigid airships, has been continued, and improvements have been made in such fabrics, in lowering the diffusion and lengthening the durability upon exposure. Continuation of the investigation of fuels based upon absolute alcohol-gasoline mixtures has resulted in further information on this subject, these fuels being in commercial use at two stations.

A series of studies have indicated the necessity of protecting magnesium alloys with coatings, and suitable protective coatings have been developed for this purpose. A rather extensive test has also been made to develop the best kind of antifouling paints for the bottoms of aircraft that remain moored for a considerable period of time in barnacle-infested waters. The type of coating developed has proved not only suitable for this purpose but has satisfactorily withstood alternate exposure to air and water. Experimental work has been carried out in the production of newer methods of doping wing fabrics to increase the tautness and durability, with very encouraging results. A great many exposure tests are now under way in this direction, which it is felt will afford considerable valuable information.

At the Bureau of Standards extensive investigations have been conducted during the past year in the development of experimental gas cell fabrics for rigid airships. Two of the experimental fabrics being developed have yielded most promising results, both of these being almost completely impervious to hydrogen and helium. One of these fabrics has already been subjected to an outdoor exposure test, under outer cover cloth, over a period of nine months, during the coldest winter and the hottest summer months, without any increase in permeability to gases, and with but little change in physical appearance, breaking strength, etc. A large number of samples of the other type of fabric mentioned above are being prepared for outdoor exposure. The bureau is also cooperating in the various work being done in the production of the numerous types of coatings. It has examined various types of fabrics submitted to the Bureau by the Navy Department for permeability and breaking strength tests. It has also been active in the examination of dopes.

SUBCOMMITTEE ON WOODS AND GLUES

The Forest Products Laboratory of the Department of Agriculture conducts practically all investigations on the application of woods and glues to aircraft construction. Most of the investigations are undertaken at the request of the Bureau of Aeronautics, Navy, or the engineering division of the Army Air Service. The following are some of the more important investigations.

Form factors for wing beams.—The Forest Products Laboratory has completed the fundamental study of form factors and stresses in bending which has resulted in the development of formulas for accurately computing the form factors of various sections.

On recommendation of the subcommittee on materials for aircraft, the National Advisory Committee for Aeronautics has published the results of this investigation in three reports:

Technical Report No. 180. The Influence of the Form of a Wooden Beam on its Stiffness and Strength: I. Deflection of Beams with Reference to Shear Deformations.

Technical Report No. 181. The Influence of the Form of a Wooden Beam on its Stiffness and Strength: II. Form Factors of Beams Subjected to Transverse Loading Only.

Technical Report No. 188. The Influence of the Form of a Wooden Beam on its Stiffness and Strength: III. Stresses in Wood Members Subjected to Combined Column and Beam Action.

The complete report of this investigation gives the results of a thorough and carefully conducted study of the mechanics of wooden beams and presents data which are of fundamental importance in airplane wing design.

Toughness tests for airplane woods.—Toughness tests on woods used in airplane construction have been continued during the past year. In the inspection of wood for airplanes a method has been found for a simple and expeditious mechanical test which can be applied to each piece to determine its acceptability. A toughness testing machine developed by the Forest Products Laboratory has given most satisfactory results.

The toughness value as obtained from this machine reflects the relation of tensile to compressive strength, while specific gravity gives an indication of the compressive strength as well as most of the other strength properties. The toughness test together with the specific gravity determination constitutes an excellent means of separating material low in strength from that of average or high strength properties and serves as an efficient means for making acceptance tests.

Studies have also been made to find a satisfactory basis for inspection and selection of suitable propeller materials. The material so far studied are white oak, yellow birch, and black walnut. The inspection method suggested provides for two acceptance toughness values for each species. Those specimens having a toughness value above the higher value set are accepted without further inspection and specimens having a toughness value between the two acceptance values set must also pass the specific gravity requirement, while those below the lowest acceptance value are rejected. This method has proved very successful in that only satisfactory material now enters into the construction of propellers.

Determination of fundamental design factors in lattice truss and plywood forms.—This investigation has been carried on with special reference to wing rib design. Considerable advance has been made in the study of wing ribs which better enable one to select the type of rib to be used under different conditions. The investigations to date on lattice, truss, and plywood wing ribs have been very general, and the tests were planned with the thought that the final analysis would lead to the development of fundamental principles of rib design. A great deal of work was done by the Forest Products Laboratory on the form of members in the lattice type of rib and comparisons of plywood and truss types were made for various airfoils and chord lengths. Comparison was also made between the two types at various heights, parallel in chord and sections of constant length in view of determining the limits at which to change from one type of construction to the other. The analysis of results has not been completed and no definite conclusions have as yet been drawn. The investigation of this problem will be continued on the development of a light web material to replace the ply-web material now used. The distribution of material as determined by the form of the member and the attachment of one member to another will also receive further attention.

Effects of stains, molds, and decay on the mechanical properties of wood.—The purpose of this investigation was to study the effect of fungi on the mechanical properties of the principal woods used in the airplane industry, to further study the fungi themselves and to work out

means for detecting fungous infection in its early stages, and to study the control or prevention of such infections. Many tests have been made during the past year on infected spruce. An important, destructive storage rot on spruce was studied both in pure cultures and with respect to the effect on the mechanical properties of the wood. The effect of four fungi on the mechanical properties of Douglas fir has been tested with the toughness machine and these results are ready for analysis. The study of the effect of yellow stain fungi on the mechanical properties of commercial white oak are practically completed. The fundamental data on the relation of fungous infection to the mechanical properties have been obtained.

Use of plywood in wing beams.—The Forest Products Laboratory from the data compiled during the past year on the shearing strength of plywood found that it is desirable to use for webs in I and box beams the plywood with the face of the grain at an angle of about 45° with the length of the beam. A series of tests of wing beams for a large bombing airplane show that box and double I sections of plywood webs give fully as good, if not better, results than the original Warren truss type.

The further study of the use of plywood in wing beams should be made of several different types and sizes to secure data on the strength and rigidity of beams with plywood of different construction and to determine the proper relation between the thickness of webs and the depth of the flange for different cross sections. Consideration should also be given to the use and effect of diaphragm construction of various types and sizes of beams.

Causes of brashness in wood.—The Forest Products Laboratory investigations into the cause and means of detecting brashness in airplane woods have been continued, but no ready visual means have been found for detecting brashness with certainty. The most reliable means of eliminating brash material is by the use of the toughness testing machine. In the study of brashness by the use of the testing machine, tests were made on white oak, yellow birch, black walnut, and Sitka spruce, and as a result of these tests the laboratory has established limits for acceptance of the material.

Development of waterproof glues.—The cold pressed blood albumen glue has been developed to a point where it can be recommended for limited use with thin veneer, but consistent results are not being obtained with heavier stock. The results obtained in experiments to date indicate that the cold pressed blood albumen glue has possibilities exceeding those of any other glue now available, and an effort should be made to perfect this glue to a point where it can safely be recommended for general use.

The study of methods of bending wood and their influence on strength.—The bending of wood is of considerable importance inasmuch as a serious loss of strength may result through the use of improper methods. A small amount of work has been done on this investigation to secure preliminary data in connection with the bending of airplane stock, such as longerons, and it is expected that the project will be continued, especially a study of the fundamental factors involved in the bending of wood and the development of a method which will result in a maximum ability to retain form.

PART IV

TECHNICAL PUBLICATIONS OF THE COMMITTEE

On recommendation of the committee on publications and intelligence, the National Advisory Committee for Aeronautics has authorized the publication of 24 technical reports during the past year. The reports cover a wide range of subjects on which research has been conducted under the cognizance of the various subcommittees, each report having been approved by the subcommittee concerned and recommended to the executive committee for publication. The technical reports presented represent fundamental research in aeronautics carried on at different aeronautical laboratories in this country, including the Langley Memorial Aeronautical Laboratory, the aeronautical laboratory at the Washington Navy Yard, the Bureau of Standards, the Forest Products Laboratory, the Stanford University, and the Massachusetts Institute of Technology.

To make immediately available technical information on experimental and research problems, the National Advisory Committee for Aeronautics has authorized the issuance in mimeographed form of another series known as "Technical Notes," of which 45 have been issued during the past year. A list of the technical notes issued during the fiscal year follows the summary of technical reports.

The Office of Aeronautical Intelligence, in addition to issuing technical reports and technical notes, has issued translations and reproductions of important technical articles of a miscellaneous character. These have been issued in mimeographed form, and the number of requests for and the importance of these papers resulted in an action of the executive committee authorizing the committee on publications and intelligence to issue translations and technical articles to be known as "Technical Memorandums" of the National Advisory Committee for Aeronautics. In accordance with this authorization, the committee has issued 50 technical memorandums on subjects that were of immediate interest not only to research laboratories but also to airplane manufacturers. A list of technical memorandums issued during the year follows the list of technical notes.

Summaries of the 24 technical reports issued during the past year, and lists of the technical notes and technical memorandums issued during the past year follow.

SUMMARIES OF TECHNICAL REPORTS

The first annual report of the National Advisory Committee for Aeronautics contained Technical Reports Nos. 1 to 7; the second annual report, Nos. 8 to 12; the third annual report, Nos. 13 to 23; the fourth annual report, Nos. 24 to 50; the fifth annual report, Nos. 51 to 82; the sixth annual report, Nos. 83 to 110; the seventh annual report, Nos. 111 to 132; the eighth annual report, Nos. 133 to 158; the ninth annual report, Nos. 159 to 185; and since the preparation of the ninth annual report the committee has issued the following technical reports, Nos. 186 to 209:

Report No. 186, entitled "The Application of Propeller Test Data to Design and Performance Calculations," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.—This report is a study of a test data on a family of Durand's propellers (Nos. 3, 7, 11, 82, 113, 139), which is fairly representative of conventional design. The test data are so plotted that the proper pitch and diameters for any given set of conditions are readily obtained. The same data are plotted in other forms which may be used for calculating performance when the ratio of pitch to diameter is known. These new plots supply a means for calculating the performance, at any altitude, of airplanes equipped with normal or supercharged engines.

The coefficients used and the methods of plotting adopted in this report coordinate the results of a few tests into complete families of curves covering the entire range of p/D ordinarily used. This method of analyzing test data enables an investigator to plan tests systematically and leads to useful application of test data.

Report No. 187, entitled "Flame Speed and Spark Intensity," by D. W. Randolph and F. B. Silsbee, Bureau of Standards.—This report describes a series of experiments undertaken to determine whether or not the electrical characteristics of the igniting spark have any effect on the rapidity of flame spread in the explosive gas mixtures which it ignites. The results show very clearly that no such effect exists. The flame velocity in carbon-monoxide oxygen, acetylene oxygen, and gasoline-air mixtures was found to be unaffected by changes in spark intensity from sparks which were barely able to ignite the mixture up to intense condenser discharge sparks having fifty times this energy.

Report No. 188, entitled "Stresses in Wood Members Subjected to Combined Column and Beam Action," by J. A. Newlin and G. W. Trayer, Forest Products Laboratory.—This report is one of a series of three reports prepared by the Forest Products Laboratory of the Department of Agriculture. The purpose of these papers is to make known the results of tests to determine the properties of wing beams of standard and proposed sections, conducted by the Forest Products Laboratory and financed by the Army and the Navy.

Report No. 189, entitled "Relation of Fuel-Air Ratio to Engine Performance," by Stanwood W. Sparrow, Bureau of Standards.—The tests upon which this report is based were made at the Bureau of Standards between October, 1919, and May, 1923. From these it is concluded that—(1) with gasoline as a fuel, maximum power is obtained with fuel-air mixtures of from 0.07 to 0.08 pound of fuel per pound of air; (2) maximum power is obtained with approximately the same ratio over the range of air pressures and temperatures encountered in flight; (3) nearly minimum specific fuel consumption is secured by decreasing the fuel content of the charge until the power is 95 per cent of its maximum value.

Presumably this information is of most direct value to the carbureter engineer. A carbureter should supply the engine with a suitable mixture. This report discusses what mixtures have been found suitable for various engines. It also furnishes the engine designer with a basis for estimating how much greater piston displacement an engine operating with a maximum economy mixture should have than one operating with a maximum power mixture in order for both to be capable of the same power development.

Report No. 190, entitled "Correcting Horsepower Measurements to a Standard Temperature," by Stanwood W. Sparrow, Bureau of Standards.—The relation between the temperature of the air at the entrance to the carbureter and power developed by the engine is discussed. Its scope is limited to a consideration of the range of temperatures likely to result from changes of season, locality, or altitude, since its primary aim is the finding of a satisfactory basis for correcting power measurements to a standard temperature.

The tests upon which this report is based were made upon aviation engines in the altitude laboratory of the Bureau of Standards. From the results of over 1,600 tests it is concluded that if calculations be based on the assumption that the indicated horsepower of an engine varies inversely as the square root of the absolute temperature of the carbureter air, the values obtained will check closely experimental measurements. The extent to which this relationship would be expected from theoretical considerations is discussed and some suggestions are given relative to the use of this relationship in correcting horsepower measurements.

Report No. 191, entitled "Elements of the Wing Section Theory and of the Wing Theory," by Max M. Munk, National Advisory Committee for Aeronautics.—This report contains those results of the theory of wings and of wing sections which are of immediate practical value. They are proved and demonstrated by the use of the simple conceptions of "kinetic energy" and "momentum" only, familiar to every engineer; and not by introducing "isogonal transformations" and "vortices," which latter mathematical methods are not essential to the theory and better are used only in papers intended for mathematicians and special experts.

Report No. 192, entitled "Charts for Graphical Estimation of Airplane Performance," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.—This report was prepared in order to simplify the estimation of airplane performance. Charts are given for estimating propeller diameter and efficiency, maximum speed, initial rate of climb, absolute ceiling, service ceiling, climb in 10 minutes, time to climb to any altitude, maximum speed at any altitude and endurance. A majority of these charts are based on the equations given for convenience. It must, of course, be understood that the charts giving propeller diameter, maximum speed, initial rate of climb, absolute ceiling, and speeds at altitudes are approximations subject to considerable error under certain conditions. These particular charts should not be used as a substitute for detailed calculations when accuracy is required as, for example, in military or naval proposals.

Report No. 193, entitled "Pressure Distribution over the Wings of an MB-3 Airplane in Flight," by F. H. Norton, Langley Memorial Aeronautical Laboratory.—This investigation was carried out to determine the distribution of load over the wings of a high-speed airplane under all conditions of flight. In particular it was desired to find the pressure distribution during level flight, over the portions of the wings in the slipstream and, during violent maneuvers, over the entire wing surface. The research was conducted at Langley Field by the National Advisory Committee for Aeronautics at the request of and with funds provided by the Army Air Service.

The method used, similar to that described in N. A. C. A. Report No. 148, consisted in connecting a number of holes in the surface of the wings to recording multiple manometers mounted in the fuselage of the airplane. In this way simultaneous records could be taken on all of the holes for any desired length of time.

The results obtained in this investigation may be briefly summarized as follows:

1. There occur in the slipstream in level flight, positive values of lift of 100 lb./sq. ft. at the leading edge of the upper wing and negative values of over 60 lb./sq. ft. on the leading edge of the lower right wing and the trailing edge of the lower left wing. Approximately 80 per cent of the load at any point is due to reduction of pressure on the upper side, tending to pull the fabric away from the supporting frame.
2. The values of lift on the ailerons and wing tips in a sharp aileron roll are only slightly greater than in steady flight.
3. The lift given by the wings when suddenly flattened out of a dive is about 80 per cent of the total dynamic load on the airplane, the fuselage and tail carrying the remainder. The lift per square foot on the upper and lower wings under these conditions is in the ratio of 4 to 3.
4. The center of pressure coefficient on the upper wings remains under all conditions at about 0.03. On the lower wing it varies between 0.53 and 0.82.
5. The distribution of lift along the span (moments taken about center line) is substantially equivalent to a uniform distribution under all conditions.

Report No. 194, entitled "Investigation of Slipstream Velocity," by J. W. Crowley, jr., Langley Memorial Aeronautical Laboratory.—These experiments were made by the National Advisory Committee for Aeronautics at the request of the Bureau of Aeronautics, Navy Department, to investigate the velocity of the air in the slipstream in horizontal and climbing flight to determine the form of expression giving the slipstream velocity in terms of the air speed of the airplane. The method used consisted in flying the airplane both on a level course and in climb at full throttle and measuring the slipstream velocity at seven points in the slipstream for the whole speed range of the airplane in both conditions. In general the results show that for both conditions—i. e., horizontal and climbing flights—the relation between the slipstream velocity V_s and airspeed V can be represented by straight lines, and consequently the equations are of the form

$$V_s = mV + b.$$

Where m and b are constants.

Report No. 195, entitled "Standardization Tests of N. A. C. A. No. 1 Wind Tunnel," by Elliott G. Reid, Langley Memorial Aeronautical Laboratory.—The tests described in this report were made in the 5-foot atmospheric wind tunnel of the National Advisory Committee for Aeronautics at Langley Field, with the primary object of collecting data on the characteristics of this tunnel for comparison with those of others throughout the world, in order that, in the future, the results of tests made in all the principal laboratories may be interpreted, compared, and coordinated on a basis of scientifically established relationships, a process hitherto impossible due to the lack of comparable data.

The work includes tests of a disk, spheres, cylinders, and airfoils, explorations of the test section for static pressure and velocity distribution, and determination of the variations of air flow direction throughout the operating range of the tunnel.

Report No. 196, entitled "Comparison of Model Propeller Tests with Airfoil Theory," by William F. Durand and E. P. Lesley, Stanford University.—The purpose of the investigation covered by the present report was the examination of the degree of approach which may be anticipated between laboratory tests on model airplane propellers and results computed by the airfoil theory, based on tests of airfoils representative of successive blade sections.

It is known that the corrections for angles of attack and for aspect ratio, speed, and interference rest either on experimental data or on somewhat uncertain theoretical assumptions. The general situation as regards these four sets of corrections is far from satisfactory, and while it is recognized that occasion exists for the consideration of such corrections, their determination in any given case is a matter of considerable uncertainty. There exists at the present time no theory generally accepted and sufficiently comprehensive to indicate the amount of such corrections, and the application to individual cases of the experimental data available is, at best, uncertain.

While the results of this first phase of the investigation are less positive than had been hoped might be the case, nevertheless the establishment of the general degree of approach between the two sets of results which might be anticipated on the basis of this simpler mode of application seems in any event to have been desirable and to have abundantly justified the time and effort required.

Report No. 197, entitled "A New Relation Between the Induced Yawing Moment and the Rolling Moment of an Airfoil in Straight Motion," by Max M. Munk, National Advisory Committee for Aeronautics.—In this paper, the induced yawing moment, due to the rolling moment produced by the ailerons, is computed. This induced yawing moment is the greatest part of the entire yawing moment encountered by the wings. The following approximate formula results:

$$\frac{\text{Induced yawing moment}}{\text{Rolling moment}} \text{ is about } \frac{\text{Lift coefficient}}{\text{Aspect ratio}}$$

Report No. 198, entitled "Astronomical Methods in Aerial Navigation," by K. Hilding Beij, Bureau of Standards.—This report was prepared by the aeronautic instruments section of the Bureau of Standards at the request of the National Advisory Committee for Aeronautics. A part of the material was made available, by the courtesy of the War Department, from the results of investigations carried out at the Bureau of Standards for the Army Air Service.

The astronomical method of determining position is universally used in marine navigation and may also be of service in aerial navigation. The practical application of the method, however, must be modified and adapted to conform to the requirements of aviation. Much of this work of adaptation has already been accomplished, but, being scattered through various technical journals in a number of languages, is not readily available. This report is for the purpose of collecting under one cover such previous work as appears to be of value to the aerial navigator, comparing instruments and methods, indicating the best practice, and suggesting future developments.

The various methods of determining position and their application and value are outlined, and a brief résumé of the theory of the astronomical method is given. Observation instru-

ments are described in detail. A complete discussion of the reduction of observations follows, including a rapid method of finding position from the altitudes of two stars. Maps and map cases are briefly considered. A bibliography of the subject is appended.

Report No. 199, entitled "Interference Tests on an N. A. C. A. Pitot Tube," by Elliott G. Reid, Langley Memorial Aeronautical Laboratory.—In connection with the standardization of instruments used in the wind tunnel, this investigation was undertaken to determine the nature and magnitude of the errors inherent in the measurement of air speed by a Pitot tube when the instrument is mounted close to some other body. The mounting of the instrument in proximity to some other body is so frequent in flight and in wind tunnel research that it seemed advisable to investigate thoroughly the magnitude of the possible errors caused by such proximity. The results of this investigation will facilitate comparisons of the errors due to interference which have been reduced to percentages of the air-speed readings obtained under conditions of no interference.

Report No. 200, entitled "Some Problems on the Lift and Rolling Moments of Airplane Wings," by James Blaine Scarborough.—This report deals for the most part with the application of the airfoil and twisted wing theory to the calculation of the lift and rolling moment of airplane wings. Most of the results arrived at are strictly true only for wings of elliptic plan form. The investigation aims to give some indications of the accuracy with which the results can be applied to the wing forms in actual use.

Report No. 201, entitled "The Effects of Shielding the Tips of Airfoils," by Elliott G. Reid.—Tests have recently been made at Langley Memorial Aeronautical Laboratory to ascertain whether the aerodynamic characteristics of an airfoil might be substantially improved by imposing certain limitations upon the air flow about its tips.

All of the modified forms were slightly inferior to the plain airfoil at small lift coefficients; however, by mounting thin plates, in planes perpendicular to the span, at the wing tips, the characteristics were improved throughout the range above three-tenths of the maximum lift coefficient. With this form of limitation the detrimental effect was slight; at the higher lift coefficients there resulted a considerable reduction of induced drag and, consequently, of power required for sustentation. The slope of the curve of lift versus angle of attack was increased.

Report No. 202, entitled "The Sparking Voltage of Spark Plugs," by F. B. Silsbee, Bureau of Standards.—This report has been prepared in order to collect and correlate into convenient and useful form the available data on this subject. The importance of the subject lies in the fact that it forms the common meeting ground for studies of the performance of spark generators and spark plugs on the one hand and of the internal-combustion engines on the other hand. While much of the data presented was obtained from various earlier publications, numerous places were found where necessary data were lacking, and these have been provided by experiments in gasoline engines at the Bureau of Standards.

The principal variables which affect the sparking voltage are the length of the spark gap, shape of the electrodes, gas density, electrode temperature, mixture ratio and turbulence. The report also contains a brief description of the time lag effects in spark gaps, which is particularly important in the case of the standard gaps used in testing ignition apparatus.

Report No. 203, entitled "Accelerations in Flight," by J. H. Doolittle of the Army Air Service.—This paper was presented to the Massachusetts Institute of Technology in partial fulfillment of the requirement for the degree of master of science.

This work on accelerometry was done at McCook Field for the purpose of continuing the work done by other investigators and obtaining the accelerations which occur when a modern high-speed pursuit airplane is subjected to the more common maneuvers.

The accelerations obtained in suddenly pulling out of a dive with well-balanced elevators are shown to be within 3 or 4 per cent of the theoretically possible accelerations.

The maximum acceleration which a pilot can withstand depends upon the length of time the acceleration is continued. It is shown that he experiences no difficulty under the instantaneous accelerations as high as 7.8 g., but when under accelerations in excess of 4.5 g., continued for several seconds, he quickly loses his faculties.

Report No. 204, entitled "Forces on Airships in Gusts," by C. P. Burgess, Bureau of Aeronautics, Navy Department.—In this report it is shown that in determining the instantaneous angle of pitch, the acceleration of the gust is as important as its maximum velocity or yaw. Hitherto it has been assumed that the conditions encountered in gusts could be approximately represented by considering the airship to be at an instantaneous angle of yaw or pitch (according to whether the gust is horizontal or vertical), the instantaneous angle being $\tan^{-1}(v/V)$, where v is the component of the velocity of the gust at right angles to the longitudinal axis of the ship, and V is the speed of the ship. An expression is derived for this instantaneous angle in terms of the speed and certain aerodynamic characteristics of the airship, and of the maximum velocity and the acceleration of the gust, and the application of the expression to the determination of the forces on the ship is illustrated by numerical examples.

Report No. 205, entitled "The Effect of Changes in Compression Ratio upon Engine Performance," by Stanwood W. Sparrow, Bureau of Standards.—This report is based upon engine tests made at the Bureau of Standards during 1920, 1921, 1922, and 1923. The majority of these tests were of aviation engines and were made in the altitude laboratory. For a small portion of the work a single cylinder experimental engine was used. This, however, was operated only at sea-level pressures.

The reports shows that an increase in brake horsepower and a decrease in the pounds of fuel used per brake horsepower hour usually results from an increase in compression ratio. This holds true at least up to the highest ratio investigated, 14 to 1, provided there is no serious preignition or detonation at any ratio. To avoid preignition and detonation when employing high-compression ratios, it is often necessary to use some fuel other than gasoline. It has been found that the consumption of some of these fuels in pounds per brake horsepower hour is so much greater than the consumption of gasoline that it offsets the decrease derived from the use of the high-compression ratio. The changes in indicated thermal efficiency with changes in compression ratio are in close agreement with what would be anticipated from a consideration of the air cycle efficiencies at the various ratios. In so far as these tests are concerned there is no evidence that a change in compression ratio produces an appreciable, consistent change in friction horsepower, volumetric efficiency, or in the range of fuel-air ratios over which the engine can operate. The ratio between the heat loss to the jacket water and the heat converted into brake horsepower or indicated horsepower decreases with increase in compression ratio.

Report No. 206, entitled "Nonmetallic Diaphragms for Instruments," by H. N. Eaton and C. T. Buckingham, Bureau of Standards.—This report, the second of a series of reports relating to the general subject of instrument diaphragms, was prepared by the Bureau of Standards at the request of the National Advisory Committee for Aeronautics. The first report of the series was published as Technical Report No. 165, "Diaphragms for Aeronautic Instruments," and comprised an outline of historical developments and theoretical principles with a discussion of expedients for making the best use of existing diaphragms.

The present report relates entirely to nonmetallic diaphragms, the use of which in certain types of pressure elements has been increasing for some time. Little, if any, information has been available, however, to aid the designer of instruments using this form of pressure element. It was to attempt to meet the need for such information that the investigation reported in this paper was undertaken.

The report describes the various materials which have been used as nonmetallic diaphragms, discusses the factors which affect the performance of the diaphragms, and gives the results of tests made for the purpose of investigating the effect produced by these factors. A theoretical discussion is given in which it is shown that the effective area of a nonmetallic diaphragm can be computed for specified conditions and hence the pressure-deflection curve can be predicted. Curves are given to facilitate the computation of effective areas under any given conditions. The theory was tested experimentally and was found accurate within about 5 per cent. Finally, pressure-deflection curves are given to illustrate the control which the designer has over the shape of the curve by varying the different parts of the pressure element.

Report No. 207, entitled "Aerodynamic Characteristics of Airfoils at High Speeds," by L. J. Briggs, G. F. Hull, and H. L. Dryden, Bureau of Standards.—This report deals with an experimental investigation of the aerodynamical characteristics of airfoils at high speeds, made at the request and with the financial assistance of the National Advisory Committee for Aeronautics. The investigation was carried out jointly by the Bureau of Standards and the Ordnance Department, United States Army, and was made possible through the courtesy of the Lynn Works of the General Electric Co., where a large centrifugal compressor was made available for the purpose.

Lift, drag, and center of pressure measurements were made on six airfoils of the type used by the Air Service in propeller design, at speeds ranging from 550 to 1,000 feet per second. The results show a definite limit to the speed at which airfoils may efficiently be used to produce lift, the lift coefficient decreasing and the drag coefficient increasing as the speed approaches the speed of sound.

The change in the lift coefficient is large for thick airfoil sections (camber ratio 0.14 to 0.20) and for high angles of attack. The change is not marked for thin sections (camber ratio 0.10) at low angles of attack for the speed range employed.

At high speeds the center of pressure moves back toward the trailing edge of the airfoil as the speed increases.

The results indicate that the use of tip speeds approaching the speed of sound for propellers of customary design involves a serious loss in efficiency.

Report No. 208, entitled "The Determination of Turning Characteristics of an Airship by Means of a Camera Obscura," by J. W. Crowley, jr., and R. G. Freeman, Langley Memorial Aeronautical Laboratory.—This investigation was carried out by the National Advisory Committee for Aeronautics at Langley Field for the purpose of determining the adaptability of the camera obscura to the securing of turning characteristics of airships, and also of obtaining some of those characteristics of the C-7 airship. The method consisted in flying the airship in circling flight over a camera obscura and photographing it at known time intervals. The results show that the method used is highly satisfactory and that for the particular maneuver employed the turning diameter is 1,240 feet, corresponding to a turning coefficient of 6.4, and that the position of zero angle of yaw is at the nose of the airship.

Report No. 209, entitled "Characteristics of a Single-Float Seaplane During Take-Off," by J. W. Crowley, jr., and K. M. Ronan, Langley Memorial Aeronautical Laboratory.—At the request of the Bureau of Aeronautics, Navy Department, the National Advisory Committee for Aeronautics at Langley Field is investigating the planing and get-away characteristics of an N-9H, a PT-1, and an F-5L, as representing, respectively, a single-float, a double-float, and a boat type of seaplane. This report covers the investigation conducted on the N-9H. The results show that a single-float seaplane trims aft in taking off. Until a planing condition is reached the angle of attack is about 15° and is only slightly affected by the controls. When planing it seeks a lower angle, but is controllable through a widening range, until at the take-off it is possible to obtain angles of 4° to 15° with corresponding speeds of 53 to 41 m. p. h. or about 40 per cent of the speed range. The point of greatest resistance occurs at about the highest angle or a pontoon planing angle of $9\frac{1}{2}^\circ$ and at a water speed of 24 m. p. h.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

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| No. | |
| 160. | Fittings and Other Structural Parts of Airplanes. By P. Eydam. Translated from Technische Berichte, Vol. III, No. 6. |
| 161. | Preliminary Study of the Damping Factor in Roll. By Lieut. James M. Shoemaker and John G. Lee, Massachusetts Institute of Technology. |
| 162. | The Arithmetic of Distribution in Multicylinder Engines. By Stanwood Sparrow, Bureau of Standards. |
| 163. | Graphic Method for Calculating the Speed and Climbing Ability of Airplanes. By Adolph Rohrbach and Edwin Lupberger. Translated from Technische Berichte, Vol. III, No. 6. |

- No.
164. General Theory of Windmills. By Max M. Munk, N. A. C. A.
 165. Tests on Riveted Joints in Sheet Duralumin. By H. F. Rettew and G. Thumin. (Abstracted and revised by John G. Lee.) Massachusetts Institute of Technology.
 166. Determination of Climbing Ability. By H. Blasius. Translated from *Technische Berichte*, Vol. III, No. 6.
 167. Wind Tunnel Tests of Five Strut Sections in Yaw. By Edward P. Warner, Massachusetts Institute of Technology.
 168. Experiments with Fabrics for Covering Airplane Wings to Determine Effect of Method of Installation. By A. Proll. Translated from *Technische Berichte*, Vol. III, No. 6.
 169. Air Resistance Measurements on Actual Airplane Parts. By C. Wieselsberger. Translated from *Technische Berichte*, Vol. III, No. 7.
 170. Reduction in Efficiency of Propellers Due to Slipstream. By Max M. Munk. Translated from *Technische Berichte*, Vol. III, No. 7.
 171. Compressive Strength of Tapered Airplane Struts. By Viktor Lewe. Translated from *Technische Berichte*, Vol. III, No. 7.
 172. The Nichols Wing Cutting Equipment. By James B. Ford. Massachusetts Institute of Technology.
 173. Significance of the Expression C_L^3/C_D^2 . By H. von Sanden. Translated from *Technische Berichte*, Vol. III, No. 7.
 174. Airplanes in Horizontal Curvilinear Flight. By Heinrich Kann. Translated from *Technische Berichte*, Vol. III, No. 7.
 175. Tests on a Model of the D Airplane T 29 of the "Deutsche Flugzeug Werke" (German Airplane Works.) By Wilhelm Molthan. Translated from *Technische Berichte*, Vol. III, No. 7.
 176. Curvilinear Flight of Airplanes. By E. Salkowski. Translated from *Technische Berichte*, Vol. III, No. 7.
 177. Note on the Relative Effect of the Dihedral and the Sweep Back of Airplane Wings. By Max M. Munk, N. A. C. A.
 178. Triplane Tests. By C. Wieselsberger. Translated from *Technische Berichte*, Vol. III, No. 7.
 179. Practical Method for Balancing Airplane Moments. By H. Hamburger. Translated from *Technische Berichte*, Vol. III, No. 7.
 180. Increasing the Compression Pressure in an Engine by Using a Long Intake Pipe. By Robertson Matthews and Arthur W. Gardiner, N. A. C. A.
 181. Interference of Multiplane Wings Having Elliptical Lift Distribution. By H. von Sanden. Translated from *Technische Berichte*, Vol. III, No. 7.
 182. Induced Drag of Multiplanes. By L. Prandtl. Translated from *Technische Berichte*, Vol. III, No. 7.
 183. Static Stability of Seaplane Floats and Hulls. By W. S. Diehl, Bureau of Aeronautics, Navy Department.
 184. Note on Vortices and on Their Relation to the Lift of Airfoils. By Max M. Munk, N. A. C. A.
 185. The Influence of Inlet Air Temperature and Jacket Water Temperature on Initiating Combustion in a High-Speed Compression Ignition Engine. By Robertson Matthews and Arthur W. Gardiner, N. A. C. A.
 186. Testing Airplane Fabrics. By A. Proll. Translated from *Technische Berichte*, Vol. III, No. 7.
 187. The Induction Factor Used for Computing the Rolling Moment Due to the Ailerons. By Max M. Munk, N. A. C. A.
 188. Longitudinal Oscillation of an Airplane: Pt. I. Problem and Method. By R. Fuchs and L. Hopf. Translated from *Technische Berichte*, Vol. III, No. 7.
 189. Torsional Strength of Nickel Steel and Duralumin Tubing as Affected by the Ratio of Diameter to Gauge Thickness. By N. S. Otey. U. S. Naval Aircraft Factory.

- No.
190. Comparing the Performance of Geometrically Similar Airplanes. By Max M. Munk, N. A. C. A., and Edward P. Warner, Massachusetts Institute of Technology.
 191. The Effect of Wind Tunnel Turbulence upon the Forces Measured on Models. By W. L. LePage and J. T. Nichols, Massachusetts Institute of Technology.
 192. Note on the Pressure Distribution over the Hull of Elongated Airships with Circular Cross Section. By Max M. Munk, N. A. C. A.
 193. High-Altitude Flying. By Paul B. King and Thomas Carroll, N. A. C. A.
 194. A Method of Determining the Dimensions and Horsepower of an Airship for Any Given Performance. By C. P. Burgess, Bureau of Aeronautics, Navy Department.
 195. On the Distribution of Lift Along the Span of an Airfoil with Displaced Ailerons. By Max M. Munk, N. A. C. A.
 196. Remarks on Pressure Distribution over the Surface of an Ellipsoid Moving Translationally through a Perfect Fluid. By Max M. Munk, N. A. C. A.
 197. Some Tables of the Factor of Apparent Additional Mass. By Max M. Munk, N. A. C. A.
 198. Micarta Propellers; Pt. I. Materials. By F. W. Caldwell and N. S. Clay.
 199. Micarta Propellers; Pt. II. Method of Construction. By F. W. Caldwell and N. S. Clay.
 200. Micarta Propellers; Pt. III. General Description of the Design. By F. W. Caldwell and N. S. Clay.
 201. Micarta Propellers; Pt. IV. Technical Methods of Design. By F. W. Caldwell and N. S. Clay.
 202. Experimental Investigation of the Effect of an Oscillating Airstream (Katzmayr Effect) on the Characteristics of Airfoils. By Toussaint, Kerneis, and Girault.
 203. A Short Method of Calculating Torsional Stresses in an Airplane Fuselage. By John E. Younger, N. A. C. A.
 204. A Study of Static Stability of Airships. By Frank Rizzo, N. A. C. A.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

- No.
231. Shortening the Landing Run. By Edward P. Warner, Massachusetts Institute of Technology.
 232. The Vertical Accelerometer, A New Instrument for Air Navigation. By Letterio Labocetta. Translated from *Atti dell'Associazione Italiana di Aerotecnica*, Vol. II, Nos. 3-4, 1922.
 233. Nieuport Astra Parachute Contest. By J. Philippe. Translated from *L'Aerophile*, July 1-14, 1923.
 234. Inherent Stability of Helicopters. By G. Arturo Crocco. Translated from *Rendicont della R. Accademia Nazionale dei Lincei*, August, 1923.
 235. Static Soaring Flight over Flat Sea Coasts. By W. Georgii. Translated from *Zeitschrift fur Flugtechnik und Motorluftschiffahrt*, July 26, 1923.
 236. Possibility of Profitable Air Traffic Between Lisbon and Rio de Janeiro. By Walter Sherz. Translated from *Luftfahrt*, July 5, 1923.
 237. Rigid Airships. By Friederich Stahl. Translated from *Flug-Welt*, Nos. 24 and 25, 1920, and Nos. 1-4 and 6-13, 1921.
 238. Monoplanes or Biplanes? By Edward P. Warner, Massachusetts Institute of Technology.
 239. Note on a New and Simple Method of Dead Reckoning in Aerial Navigation. By Louis Constantin. Translated from *L'Aerophile*, June 1-15, 1923.
 240. Rules and Regulations for Endurance Contest of Aviation Engines. (Under the Auspices of the Aero Club of France.) Translated from *Concours de Moteurs de Grande Endurance pour L'Aeronautique*.
 241. Spontaneous Combustion of Hydrogen. By Wilhelm Nusselt and Ph. Pothmann. Translated from *Zeitschrift des Verienes Deutscher Ingenieure*, No. 9, March 4, and No. 39, September 30, 1922. (Prepared by S. N. Brooks.)
 242. Factors of Safety. By Edward P. Warner, Massachusetts Institute of Technology.

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243. Aeronautical Record No. 1. (To June, 1923.) Translation of *Chronique Aeronautique*, published by the *Societe d'Etudes et d'Informations Economiques*.
244. Air Transport. By F. Handley-Page. Reprint from *The Journal of the Institute of Transport*, February, 1923.
245. Investigations of Aviation Accidents and Lessons to be Drawn from Them. By F. Devauliez. Paper read at the International Air Conference, London, June, 1923.
246. Remarks on Building of Low-Powered Airplanes. By Werner v. Langsdorff. Translated from *Der Motorwagen*, November 10, 1923.
247. Methods of Experimentation with Models and Utilization of Results. By Lieutenant Colonel Robert. Paper read before the International Air Congress, London, 1923.
248. Specializing for Record Breaking. By Edward P. Warner, Massachusetts Institute of Technology.
249. Aeronautic Instruments. By E. Everling and H. Koppe. Translated from *Zeitschrift des Vereines deutscher Ingenieure*, April 1, 1922, Vol. 66, No. 13.
250. Magnan Glider M-2. By M. Andre Lesage. Translated from *L'Air*, January 1, 1924.
251. The Vector Ruling Protractor. By A. F. Zahm. Taken from *Journal of the Franklin Institute*, February, 1924, Vol. 197, No. 2.
252. Effect of Changing the Mean Camber of an Airfoil Section. By A. Toussaint, March, 1924. Translated from *La Technique Aeronautique*, October 15 and November 15, 1923.
253. Voyage of the Dixmude over Northern Africa. By Lieutenant Lemaire. Translated from *La Technique Aeronautique*, January 15, 1924.
254. The Practical Difficulties of Commercial Flying. By F. T. Courtney. Paper read before the Royal Aeronautical Society, Scottish Branch.
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BIBLIOGRAPHY OF AERONAUTICS

During the year 1923 the committee issued a bibliography of aeronautics covering the years 1917, 1918, and 1919 in one volume. It had previously issued a bibliography covering the years 1910 to 1916 in one volume. The bibliography for the years 1920 and 1921 in one volume will soon be ready for distribution. The bibliography for 1922 is in the hands of the printer, and should also be issued during the coming year. It is the policy of the committee to prepare and publish thereafter an annual bibliography.

Citations of the publications of all nations are included in the language in which the publications originally appeared. The arrangement is in dictionary form, with author and subject entry, and one alphabetical arrangement. Detail in the matter of subject-reference has been omitted on account of cost of presentation, but an attempt has been made to give sufficient cross reference to make possible the finding of items in special lines of research.

PART V

THE PRESENT STATUS OF AVIATION

THE PRESENT STATE OF TECHNICAL DEVELOPMENT

Science of aerodynamics.—Very satisfactory progress has been made during the past 10 years in the science of aerodynamics. The theory involved has been reduced to definite formulæ which in most cases are found to meet requirements.

The nature of air forces is fairly well understood, and the various types of air flow may be studied analytically.

The methods of wind tunnel testing and the interpretation of wind tunnel results are practically standardized.

A large number of excellent wing sections have been developed. From wind tunnel and free flight investigations a good "working knowledge" of the forces and moments on an airplane is available.

A study of the present state of knowledge in aerodynamics and the limitations imposed on the performance that can be obtained with the present airplane discloses the lines along which future investigations must be carried out.

The conventional type of airplane is limited in its performance by the following factors: The power-weight ratio, strength of structure, the characteristics of the wing sections, controllability and maneuverability, and unknown facts concerning factors at high speeds and accelerations.

Airplane performance is limited by the strength of the structure in that an increase in strength will mean an increase in weight, unless better methods of construction or better materials are used. This is a problem of the greatest importance, and is so tied up with other factors that its solution depends upon exact knowledge of stresses if the structural weight is to be safely reduced.

To make it possible to compute accurately the stresses in an airplane structure, an exact knowledge of the magnitude and distribution of the loads over an airplane's wings and control surfaces under various conditions of flight must be known. It is imperative that this knowledge be made available, especially for the design of high-speed airplanes of the pursuit type. The load factor used in the design of pursuit type airplanes is 12, and in flight, accelerations of 8 g. have been recorded, indicating how near it is possible to approach a loading which will cause structural failure.

The number of failures of control surfaces also indicates the necessity of an exact knowledge of the loads or forces acting on the control surfaces and their relation to the forces on the lifting surfaces. This information will greatly assist in the development of much needed design factors for control surfaces.

Control at low speed is a matter of great importance, both for commercial and military types of airplanes, as such control would greatly increase safety in landing and taking off. This subject has received very little consideration in this country, and the problem of increasing the effectiveness of aileron and rudder control at low speeds demands immediate attention.

Associated with the question of control at low speed is the problem of reducing the landing speed. A study must be made of reducing landing speeds by the use of flaps and slots, but in such study consideration should be given to the practical limitation of each device, since aerodynamically a device may give great promise and yet at the same time involve such an increase in weight or change of structure as to make it impractical.

The present trend of development in airplane design and construction is toward safety and reliability. In the past too much importance has been attached to the obtaining of a high power-weight ratio; in new designs a reserve of power should be provided and the designs should further provide for operation of the engine at a fraction of its maximum power output in normal flight, which will greatly increase the life and reliability of the engine, "the heart of the airplane."

Airplane structures.—The question of the relative merits of biplane and monoplane construction is continually coming up for discussion. In 1923 the monoplane seemed to be gaining in favor, but in the types then constructed so much difficulty with fluttering of the wings was encountered at high speed that the trend of American design is definitely away from monoplanes. To avoid wing flutter at high speed, a monoplane wing must be built extremely rigid in torsion, which requirement practically makes necessary the use of either a metal or wooden covering for the surface of the wing.

In this country there is also a strong preference for the biplane in design for the slower military types of observation and bombing airplanes. Wing flutter is not likely to give trouble here, but there are other considerations which favor the biplane. In the first place, it is rather difficult to secure good lateral control in monoplanes; secondly, the wing structure can usually be built with less weight in a biplane; and thirdly, the biplane gives a more compact airplane which takes up less hangar space and is more easily handled. This latter point is of particular importance in the design of naval aircraft which have to be handled aboard ship.

As a commercial airplane, the monoplane seems to be a preferred type, especially for passenger carrying. This is no doubt due to the fact that with a monoplane wing placed near the top of the fuselage, it is possible to arrange the seating of the passengers so as to give an unobstructed view below the airplane.

Materials—Metal construction.—A considerable advance has been made in the application of metal construction to aircraft in spite of the fact that progress has been retarded by the high cost of experimental work and the scarcity of orders for metal aircraft in quantity.

Metal construction was first tried out on tail surfaces and landing gear, probably because of the small size and comparative simplicity of these units. To-day it is common practice to use metal for the structural members of the landing gear and the tail surfaces, although the fabric covering of the surfaces has usually been retained.

The next step was the development of the metal engine mounting which was the precursor of the metal fuselage. In most of the recent designs metal construction of some sort has been used in the fuselage. A framework of mild steel tubes with a fabric covering is the most common type. There is much variation in the details of the fuselage frames; some designers use wires for their diagonal bracing, some use tubes throughout, some make all joints by welding, while others weld the vertical and diagonal members to fittings which are pinned and sweated to the longerons. The surprising thing is the bold dependence upon welding for the security of important joints. Welding is being used to-day as a matter of course in places where a few years ago its use would be prohibited.

Fuselages of steel-tube construction are more durable than the old wood and wire construction, offer better protection to the crew in the case of a crash, and are cheaper to construct. They do not afford, however, any material saving in weight. Duralumin construction is more promising in regard to reducing weight, and a number of different types are being tried out including both the tubular truss construction and the shell type of construction consisting of a duralumin skin which is backed up with internal framing.

The extension of metal construction to wings has lagged behind fuselages, possibly because the conventional wood and fabric combination has proven very satisfactory for the climatic conditions under which American airplanes operate. Then, too, the problem is a more difficult one. A number of experimental wings has been constructed using steel or duralumin for the principal members, some with the fabric covering and others with a duralumin skin. None has been built in quantity, however, except the MO-1 wings which have built-up duralumin girders for the wing beams and use wooden ribs and fabric covering. An increase in the use of metal

for wings is to be anticipated, especially in the heavier types of aircraft. Duralumin is likely to be the chief metal used.

Aircraft engines.—The successful progress in aircraft development is reflected in the fact that we now have in this country eight proved engines in horsepowers ranging from 60 to 800.

The development of engines is in three stages—the experimental stage, the flight test stage, and the production stage.

For a horsepower range of 60 to 200 there is available the Wright air-cooled, 3-cylinder radial 60 h. p. engine, the Wright air-cooled, 9-cylinder radial 200 h. p. engine, and the Wright water-cooled 8-cylinder 200 h. p. engine. All these engines are in the production stage and are proved engines.

From 300 h. p. to 400 h. p. the Curtiss D-12, a 12-cylinder water-cooled engine, is in the production stage and has given an excellent performance, especially in pursuit type airplanes.

From 400 h. p. to 500 h. p. two engines are available, the proved Liberty 12 and the Packard 1A-1500. The latter engine is still in the flight test stage and gives every indication of being one of the most reliable and lightest engines ever developed.

The Wright 12-cylinder T-3 engine answers present requirements for horsepower from 450 to 600. This engine is in the production stage.

From 600 to 800 h. p. the Packard 1A-2500 12-cylinder water-cooled engine answers present requirements. Its performance is excellent and its weight per horsepower low. It is still in the experimental stage, however.

Two 400 h. p. radial air-cooled engines are in the experimental stage. The two engines are being developed by different engine builders. The tests of these engines in service will answer the question of whether the 400 h. p. radial air-cooled or the 400 h. p. water-cooled engine is better suited for certain military types of aircraft.

In the development of new engines for the services there seems to be no immediate demand for high-power engines over 1,000 h. p. The new development will be along lines of improving present types with a view to increasing reliability and decreasing the weight per horsepower.

Airships.—The technical development of airships during the past six years both from an aerodynamical and constructional standpoint has been steady and the progress satisfactory. In experimental research with reference to improved design and operation of airships the United States has now taken the lead.

The technical staff of the Bureau of Aeronautics has developed satisfactory design theories for the general design of the structure of rigid airships as embodied in the *Shenandoah*.

The engineering division of the Army Air Service has supervised the design and construction of the *RS-1*, a large semirigid airship now nearing completion. The development of this airship has been carefully planned, taking advantage of all available facilities.

The National Advisory Committee for Aeronautics, at the request first of the Bureau of Aeronautics and later of the Army Air Service, appointed special airship committees to report on the design and construction of both rigid and semirigid airships. The committee was made up of prominent engineers and resulted in extending the interest and knowledge of airship design and construction. The work of the two committees is the first intensive study of the airship by competent engineers not directly connected with an airship problem as such.

In the course of the airship development program an extensive series of tests was carried out by the Bureau of Standards to develop accurately the properties of the various parts of rigid airships. Further, the design theories developed have been supplemented by tests of a photo-elastic model of the structure of a rigid airship, and further confirmation of these theories has been found in the results of a series of strain gauge measurements carried out on the *Shenandoah*.

One of the fields in which the greatest progress has been made has been the determination of the magnitude of the aerodynamic loads encountered by airships. The Navy requested the National Advisory Committee for Aeronautics to determine the air pressure, and hence the loads, actually sustained by an airship envelope, fins and rudders, in flight and in maneuvering. A long series of tests were carried out by the technical staff of the committee on the airship *C-7*.

These experiments have produced a wealth of valuable information, laying the foundation for the designer in determining the aerodynamic loads on airships.

When the construction of a rigid airship was undertaken by the Navy one of the most difficult problems faced was the production in this country of duralumin, the aluminum alloy so successfully used in the construction of the German airships. Due to the efforts of the Navy duralumin is now being successfully made and its manufacture is now established on a solid footing.

Next to duralumin the most difficult material to obtain was the fabric used in making gas cells for airships. Such a fabric had never been made in this country prior to the construction of the *Shenandoah*. There are now two factories with trained personnel competent to manufacture this type of fabric in quantity. In addition substitutes for the goldbeater's skin, used in gas cell construction, have been found and two types give promise of success.

The problem of producing an airship engine in this country has been solved and there are now available two models of eminently satisfactory engines.

The development of helium production facilities has proceeded rapidly, although most of the effort has been expended on the actual production. Many valuable improvements in the process of extracting the helium have been developed and as a result it is possible to predict more efficient production at a lower cost.

With the use of helium it was necessary to develop a method for preventing the valving of the helium as the airship became lighter due to the consumption of fuel. A successful method of water recovery from the exhaust gas from the engine is now in operation. It has been possible to recover water from the exhaust gas to the extent of 1.2 pounds of water for each pound of fuel burned. This is the first time in airship history that a device of this kind has been used and it makes possible the economical use of helium gas.

The present status of airship development should not blind us to the necessity for further research. In particular, there still remains much to be known regarding the loads encountered by airships in flight. Full-size tests on the *Shenandoah* and the *Los Angeles* should be made to determine the aerodynamic loads. At the same time a study should be made on the structure of the airship by means of strain gauges. These studies are of especial importance in view of the probability that future airships will have capacities of 5,000,000 cubic feet and more.

THE GOVERNMENTAL AGENCIES CONCERNED AND WHAT THEY ARE DOING

There are four governmental agencies directly concerned with the use or development of aviation, namely:

The Army Air Service.

The Naval Bureau of Aeronautics.

The Air Mail Service.

The National Advisory Committee for Aeronautics.

THE ARMY AIR SERVICE

The Army Air Service was established in its present form by the Army reorganization act, approved June 4, 1920, and at present functions under the control of the Secretary of War as a coordinate combatant branch of the Army. The functions of the Army Air Service have been classified first, as an arm of the mobile army; second, as an arm to be used against enemy aircraft in defense of all shore establishments; and third, as an arm to be used in cooperation with other arms, or alone, against enemy vessels engaged in attacks on the coast.

The Chief of the Army Air Service has the rank of major general. The organization is divided into six main divisions, namely, personnel, information, training and war plans, industrial war plans, supply, and engineering.

The flying personnel of the Army Air Service at the present time is obtained by the assignment of graduates from West Point, by the transfer of junior officers from other arms, and by appointment after examination of applicants from civil life.

The Air Service has 845 officers with rating as airplane pilots, airplane observers, airship pilots, airship observers, or balloon observers. In addition about 51 enlisted men have the rating of airplane pilot, junior airplane pilot, or airship pilot.

The following special stations are maintained by the Army Air Service and have the functions specified:

- Brooks Field, San Antonio, Tex. (the primary flying school).
- Chanute Field, Rantoul, Ill. (the technical school).
- Kelly Field, San Antonio, Tex. (the advanced flying school).
- Langley Field, Hampton, Va. (the tactical school).
- McCook Field, Dayton, Ohio (the engineering school).
- Scott Field, Belleville, Ill. (the balloon and airship school).

In addition there are a number of other fields occupied by tactical units which are under the immediate command of the corps area commanders in the United States and under the department commanders in Hawaii, the Philippine Islands, and the Canal Zone. These units are so located that at all times the ground forces of the Army may have the aerial observation cooperation so essential in their peace-time training and when engaged in hostile operations. As a small nucleus for the development of an adequate air force capable of fulfilling that part of the mission of the Army Air Service as quoted above "as an arm to be used against enemy aircraft in defense of all shore establishments; and as an arm to be used in cooperation with other arms, or alone, against enemy vessels engaged in attacks on the coast," the Army maintains, exclusive of overseas garrisons, one bombardment, one attack, and one pursuit group at Langley, Kelly, and Selfridge Fields, respectively. These tactical air force units are engaged in the development and perfection of offensive and defensive aerial tactics, air strategy, and the concentrated application of tactical air power. With the limited forces available air defense maneuvers have only been possible of accomplishment on a small scale. The Army Air Service has repeatedly proved the value of aviation as a peace-time agency by successfully employing it in the following activities of a nonmilitary nature: Forest fire patrol; aerial surveying and mapping; in conjunction with the Department of Agriculture in combating insect pests, such as the boll weevil and gypsy moth, and in other ways.

The engineering division of the Air Service at McCook Field, Dayton, Ohio, carries on engineering experiments covering the development of airplanes, engines, armament, materials, instruments, parachutes, studies of design possibilities, night flying equipment, etc. Briefly, the engineering division conducts engineering experiments which are of direct value to the Army Air Service and in the general development of aviation. Airplanes are not manufactured by any Air Service station.

Equipment to demonstrate the practicability of night flying was developed at McCook Field and tested by 7,500 miles of night flying between Dayton and Columbus, Ohio. The results of these tests formed the basis upon which the Air Mail Service inaugurated its present successful night-flying service.

The Air Service has developed aerial photography so that it is being used by many departments of the Government. In addition to its tactical application by all branches of the Army, aerial photographs of large areas of the United States have been taken for the Geological Survey and Corps of Engineers. All such information gathered by the Air Service is made available to commercial organizations.

The Air Service has started and operated airways between some of the principal cities of the United States and has prepared data on air routes and landing fields, so that when commercial flying reaches a stage where this information is needed it can be furnished.

The Air Service also trains a number of flying cadets each year who are given reserve commissions and are thereafter available as military pilots or are well qualified to be pilots of civil aircraft.

A number of interesting and important flights, all having a military significance, have been made by the Air Service. Among these may be mentioned the Alaskan flight, various

transcontinental flights, the Porto Rican flight, the dawn-to-dusk flight, and the round-the-world flight. These flights have served their purpose and have brought home to the American people some of the possibilities of aviation.

THE NAVAL BUREAU OF AERONAUTICS

The Naval Bureau of Aeronautics was established by act of Congress approved July 12, 1921. Its functions differ from those of the Army Air Service, due to a fundamental difference in organization, in that the Army Air Service is a combatant arm of the Army with its own production and supply services, etc., whereas the Navy has no separate combatant arms, naval aviation being an integral part of the fleet. The Naval Bureau of Aeronautics is charged with all matters relating to the design, procurement, development, and maintenance of naval and Marine Corps aircraft, and the carrying into effect of the Navy Department's policies regarding naval aviation. The Naval Bureau of Aeronautics furnishes all information concerning naval aviation required by the Chief of Naval Operations, who, under the direction of the Secretary of the Navy, is charged with the operations of the fleet (including aircraft) and with the preparation and readiness of plans for its use in war.

Flying personnel and aircraft units forming the naval aviation organization afloat are under the immediate command of the commanders of the vessels to which they are attached when such vessels are acting singly, and they are under the immediate command of the senior officer present when such vessels are acting collectively. The tactical command of aircraft in flight is exercised by the senior flying officer. The mission of such aircraft is to serve the needs of the ships to which they are attached.

Provision is also made for fleet aircraft squadrons operating from airplane carriers or tenders under the immediate command of the fleet aircraft squadron commander, who is responsible to the commander in chief of the fleet. Fleet aircraft squadrons operate as parts of the fleet in the same manner as other coordinate arms of the fleet—surface craft and sub-surface craft.

Another part of the naval organization provides for aircraft assigned to the naval districts as a part of the naval coast defense forces operating under the various district commanders ashore.

The Chief of the Naval Bureau of Aeronautics has the rank of rear admiral. The organization is divided into four main divisions, namely, plans, administration, material, and flight.

Naval flying officers are selected at the present time solely from line officers of the Navy and of the Marine Corps. The present requirements are that they must be graduates of Annapolis and have had three years of sea duty before being selected for aviation duty. There are, however, a number of flying officers who entered the naval service during the war direct from civil life who have since qualified by examination as regular line officers of the Navy.

There are 630 officers attached to naval aviation, including 157 ground officers. Of the total of 630 officers, 422 are attached to naval aviation ashore and 208 are attached to naval aviation afloat.

The following special stations have the functions stated:

Naval air station, Anacostia, D. C. (experimental and test work).

Naval air station, Lakehurst, N. J. (rigid airship operation and maintenance).

Naval air detail, Newport, R. I. (experimental torpedo work).

Naval air detail, Dahlgren, Va. (experimental ordnance work).

Naval aircraft factory, navy yard, Philadelphia, Pa. (repair and maintenance; experimental and test work; storehouse and supply depot).

Naval air station, Pensacola, Fla. (training of flying personnel).

Aviation mechanical school, Great Lakes, Ill. (training of aviation mechanics).

In addition to the above, the Navy has four active and three inactive coastal air stations.

The principal activities of the Bureau of Aeronautics at the present time may be summarized as follows: Development of service types of airplanes, aircraft engines, and accessories, and their procurement, supply, and maintenance; providing naval aircraft units with the

latest approved types of airplanes and equipment; development of rigid airships by assignment of the Joint Army and Navy Board, and of other lighter-than-air activities; installing aircraft on vessels of the fleet; development of aircraft carriers; development of launching and arresting devices for airplane carriers and shipboard use; training of regular and reserve aviation personnel; aerial photography and mapping; aerological reports; maintenance of naval air stations ashore; and cooperation with the Army Air Service, the National Advisory Committee for Aeronautics, and, as far as possible, with civilian aeronautic organizations, for the furtherance of aviation development.

THE AIR MAIL SERVICE

The Air Mail Service was inaugurated May 15, 1918, the first route being between Washington and New York. It has been supported by annual congressional appropriations without having been definitely established by law.

It is a transportation service directly operated by the Post Office Department under the immediate control of the Second Assistant Postmaster General.

The personnel of the Air Mail Service totals 580, including 42 regular airplane pilots and 5 reserve pilots. The airplane pilots, as well as the other personnel, are secured direct from civil life without examination.

The flying equipment of the Air Mail Service comprises a total of 94 airplanes, of which there are 82 DH-4's used for carrying the mails, 4 inspection airplanes in good condition, and 8 others that are not serviceable.

The Air Mail stations in operation number 15, extending across the country on the route from New York to San Francisco. There is also an Air Mail general repair depot located at Chicago, employing 115 men. At this station airplanes are overhauled and rebuilt, and spare parts are stocked for all flying equipment and ground equipment, especially that needed for night flying.

In a special report of the National Advisory Committee for Aeronautics submitted to President Harding on December 20, 1922, at his request, it was stated that:

"The fundamental purpose of the Air Mail Service is to demonstrate the safety, reliability, and practicability of air transportation of the mails, and incidentally of air transportation in general. In particular, it should—

"(a) Develop a reliable 36-hour service between New York and San Francisco, and make that service self-supporting by creating the necessary demand for it and charging a rate between ordinary postage rates and night-letter telegraph rates.

"(b) Keep strict records of the cost of the service and strive in every way to reduce such costs to a minimum, thereby demonstrating the value of air transportation from an economic point of view, and in particular making it possible for private enterprise eventually to contract for the carrying of mails by airplane at a rate which not only would not exceed the income from such a service but would permit the Post Office Department to provide other postal airways to meet the demands of the people for the more rapid transportation of mail. In the present undeveloped state of the art, it would be wholly impracticable to operate an air mail service by contract."

The Air Mail Service at the present time is conducting an experimental demonstration of the practicability of night flying in the transportation of mail between New York and San Francisco by air. The ground equipment for night flying extends from Bryan, Ill., near Chicago, to Rock Springs, Wyo., near Cheyenne, and mail is being transported regularly on an approximate average of 41 hours for westbound mail and 36 hours for eastbound. The use of the service is gradually increasing, and the developments to date indicate that in a reasonable time the service will be fully self-supporting.

The development of the Air Mail Service has been a credit to American aviation. It is a practical means for aiding the development of commercial aviation as well as a means for expediting the transportation of mail. Mail is bound to be carried eventually by the fastest means available, and it is safe to say that in this age of progress the American people will demand and will support a more or less general use of aircraft in the future for carrying the mails.

THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

The National Advisory Committee for Aeronautics was created by act of Congress in 1915 as an independent establishment. It is composed of 12 members appointed by the President, all of whom serve without compensation. Its membership is drawn from official and private life as follows:

From the Government service:

Two from the War Department (the Chief of Air Service and the chief of the engineering division of the Air Service.)

Two from the Navy Department (the Chief of the Bureau of Aeronautics and the chief of the material division).

One from the Weather Bureau (the chief).

One from the Bureau of Standards (the director).

One from the Smithsonian Institution (the Secretary).

From private life:

Five who are acquainted with the needs of aeronautical science or skilled in aeronautical engineering or its allied sciences.

The organic act creating the National Advisory Committee for Aeronautics provides: "That it shall be the duty of the Advisory Committee for Aeronautics to supervise and direct the scientific study of the problems of flight, with a view to their practical solution, and to determine the problems which should be experimentally attacked, and to discuss their solution and their application to practical questions. In the event of a laboratory or laboratories, either in whole or in part, being placed under the direction of the committee, the committee may direct and conduct research and experiment in aeronautics in such laboratory or laboratories."

The committee's laboratories for the direct conduct of fundamental research in aeronautics are located at Langley Field, Va., where the facilities of a large Army flying field are added to those of a well-equipped research laboratory.

The committee operates under rules and regulations approved by the President. It elects annually its chairman and its secretary from among its members and also an executive committee, which in turn elects its chairman and its secretary. The executive committee has immediate and entire charge of the activities of the committee during the interim between the stated meetings of the entire committee.

The executive committee has established three standing technical subcommittees, namely, the committee on aerodynamics, the committee on power plants for aircraft, and the committee on materials for aircraft. The organization of these subcommittees is patterned after that of the entire committee, each having specially appointed representatives from the Army and Navy Air Services, the Langley Memorial Aeronautical Laboratory, the Bureau of Standards, and private life, all of whom serve without compensation.

It is mainly through the instrumentality of the technical subcommittees that coordination of aeronautic research and experiment and cooperation among the agencies interested are made effective. The subcommittees originate the programs for aeronautical research in their respective fields, and after such programs are approved by the executive committee the subcommittees receive progress reports periodically and keep in touch with the active workers in their respective fields and with the progress of the investigations coming under their cognizance. Through these subcommittees, and largely by virtue of the opportunity afforded by regular and official contact and personal acquaintance that result from regular attendance at meetings, complete cooperation on the part of all responsible governmental officers concerned with the investigation of technical problems in aeronautics is assured.

With the subcommittees functioning efficiently, and with their activities coordinated by the director of aeronautical research, the executive committee is enabled to devote a portion of every meeting to the informal discussion of general problems regarding the development of military and civil aviation, and these informal discussions are often of greater advantage in promoting understanding and cooperative effort than are formal or official communications.

The committee's activities in the field of aeronautical development may be stated under four headings as follows:

(a) The coordination of research and experimental work in aeronautics by the preparation of research programs and the allocation of particular problems to the various laboratories.

(b) The conduct of scientific research on the more fundamental problems of flight, under the immediate direction of the committee in its own laboratory known as the Langley Memorial Aeronautical Laboratory, at Langley Field, Va.

(c) The collection, analysis, and classification of scientific and technical data in aeronautics, including the results of research and experimental work conducted in all parts of the world.

(d) The diffusion of technical knowledge on the subject of aeronautics to the military, naval, and postal air services, aircraft manufacturers, universities engaged in the teaching of aeronautics, and the public generally.

In addition, the committee holds itself at the service of the President, the Congress, and the executive departments of the Government for the consideration of special problems in aeronautics which may be referred to it.

The success of the National Advisory Committee for Aeronautics in performing its important functions depends fundamentally upon the following facts:

1. Its members and the members of its standing subcommittees serve without compensation, the Government thus receiving the services of men who would not otherwise be available.

2. The reason why these men are willing to serve is because the committee is an independent Government establishment, reporting directly to the President, receiving its own appropriation from Congress.

3. By virtue of such status, the committee is able to initiate and to conduct any investigation which, after full discussion by the subcommittee concerned, is considered fundamental or desirable.

All these advantages would be lost were the committee to be made part of any Government department.

THE EXISTING SCHEME OF COOPERATION

ORGANIZATION

The governmental agencies for effecting cooperation and preventing duplication are:

The Joint Army and Navy Board.

The Aeronautical Board.

The National Advisory Committee for Aeronautics.

THE JOINT ARMY AND NAVY BOARD

The Joint Army and Navy Board was created in 1919 by joint order of the Secretary of War and the Secretary of the Navy "to secure complete cooperation and coordination in all matters and policies involving joint action of the Army and Navy relative to the national defense." The board is composed of three high-ranking Army officers and three high-ranking Navy officers, including the Chief of Staff of the Army and the Chief of Naval Operations. The order creating the board further provides that "It shall also have the duty of originating consideration of such subjects when in its judgment necessary; and is responsible for recommending to the Secretary of War and the Secretary of the Navy jointly whatever it considers essential to establish the sufficiency and efficiency of cooperation and coordination of effort between the Army and the Navy."

In order to provide an agency for detailed investigation, study, and development of policies, projects, and plans relative to the national defense and involving joint action of the Army and Navy, the Secretary of War and the Secretary of the Navy have further agreed:

Upon the organization of a joint Army and Navy planning committee, consisting of—

For the Army: Three or more members of the War Plans Division, General Staff, to be designated by the Chief of Staff.

For the Navy: Three or more members of the Plans Division of Naval Operations, to be designated by the Chief of Naval Operations—

the order establishing the Joint Army and Navy Board provides that "the joint Army and Navy planning committee will investigate, study, and report upon questions relative to the national defense and involving joint action of the Army and Navy referred to it by the Joint Army and Navy Board. It shall also have the duty of originating consideration of such subjects when in its judgment necessary. The members of this committee are authorized to consult and confer freely on all matters of defense and military policy in which the Army and the Navy are jointly concerned and will consider this joint work as their most important duty."

THE AERONAUTICAL BOARD

The Aeronautical Board was created in 1920 by joint action of the Secretary of War and the Secretary of the Navy, and is composed of three officers from the Army Air Service, and three officers from the Navy Bureau of Aeronautics. The following paragraphs are quoted from the order establishing the Aeronautical Board:

"To prevent duplication and to secure coordination, plans of new projects for the construction of aircraft, for experimental stations, for coastal air stations, and for stations to be used jointly by the Army and Navy, or for extensive additions thereto, shall be submitted to the Aeronautical Board for recommendation.

"The development of new types of aircraft, or of weapons to be used from aircraft, so far as practicable, shall be assigned to and carried on by one Air Service. This restriction shall not prevent the employment by either Air Service of any types of aircraft or weapons which, after development, are considered to be necessary for the accomplishment of its functions. Questions relating to the development of new types of aircraft or weapons to be used from aircraft shall be referred to the Aeronautical Board for recommendation as to which Air Service shall be charged with the development.

"All information pertaining to experiments in connection with aviation shall be exchanged promptly between the Army and Navy Air Services.

"Whenever possible, training and other facilities of either Air Service shall be made available for, or to be used by, the other service.

"Before arranging to purchase aircraft, each service shall attempt to secure aircraft of the type desired from or through the other service.

"In the interests of economy, heavier-than-air craft shall be provided in preference to nonrigid, semirigid, or rigid dirigibles whenever the former can satisfactorily perform the service required.

"All estimates of appropriations for the Army and Navy aviation programs shall be presented to the Aeronautical Board for review and recommendation before submission to Congress."

THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

The National Advisory Committee for Aeronautics functions under the President as an independent Government establishment created by act of Congress in 1915, for the supervision and direction of the scientific study of the problems of flight, with a view to their practical solution. It conducts scientific research on the more fundamental problems of flight, and in the exercise of its functions as a coordinating agency it allocates to other agencies, governmental and private, investigations in aeronautics for which they may be peculiarly fitted, thus marshaling the talent of the American people for the advancement of the science of aeronautics.

The regular and official contact, through membership on the main committee and on its various subcommittees, of representatives of the Army and Navy Air Services with each other and with specially appointed representatives of the Bureau of Standards, educational institutions, and independent enterprises that are aiding in the solution of technical problems in aeronautics, serves to prevent unnecessary duplication of effort, facilitate the interchange of ideas between different groups of workers, and develops a mutual understanding that makes for the greatest possible advancement in the science of aeronautics.

The committee's unique facilities for aeronautical research are also utilized in the making of special investigations on request of either the Army Air Service, the Naval Bureau of Aeronautics, or the Air Mail Service, and the same facilities are available for the conduct of special investigations for private firms or individuals, provided that they defray the actual cost thereof.

The committee invites special attention to the fact that the Bureau of Standards has been of great assistance in the study of technical problems in aeronautics for which it had adequate facilities. The same may be said of the Weather Bureau in the study of meteorological problems and their relation to aviation; of the Forest Products Laboratory in the study of wood problems; and of the Bureau of Mines in the development of helium. It has been the policy of the committee to assign to the Bureau of Standards investigations for which it was peculiarly well equipped, and the committee has encouraged the use of that bureau's facilities by the Army and Navy Air Services. The facilities of educational institutions, notably the Massachusetts Institute of Technology and Stanford University, have also been utilized by the Government to advantage in the investigation of aeronautic problems.

POLICY OF THE ARMY AND NAVY RELATING TO AIRCRAFT

The following policy of the Army and Navy relating to aircraft has been approved by the Joint Army and Navy Board and by the War and Navy Departments, and has been published to the services for their information and guidance.

"Aircraft to be used in the operations of war shall be designated:

"(a) Army aircraft.

"(b) Navy aircraft.

"(c) Marine aircraft.

"Army aircraft are those provided by the War Department and manned by Army personnel.

"Navy aircraft are those provided by the Navy Department and manned by Navy personnel.

"Marine aircraft are those provided by the Navy Department and manned by Marine Corps personnel.

"The marine air service is a branch of the naval air service.

"The functions of the Army, Navy, and marine aircraft are as follows:

"*Army aircraft*.—Operations from bases on shore—

"(a) As an arm of the mobile army.

"(b) Against enemy aircraft in defense of all shore establishments.

"(c) Alone or in cooperation with other arms of the Army or with the Navy, against enemy vessels engaged in attacks on the coast such as—

"I. Bombardment of the coast.

"II. Operations preparatory to or of landing troops.

"III. Operations such as mine laying or attacks on shipping in the vicinity of defended ports.

"*Navy aircraft*.—Operations from mobile floating bases or from naval air stations on shore—

"(a) As an arm of the fleet.

"(b) For overseas scouting.

"(c) Against enemy establishments on shore when such operations are conducted in cooperation with other types of naval forces, or alone when their mission is primarily naval.

"(d) To protect coastal sea communications by—

"I. Reconnaissance and patrol of coastal sea areas.

"II. Convoy operations.

"III. Attacks on enemy submarines, aircraft, or surface vessels engaged in trade prevention, or in passage through the sea area.

"(e) Alone or in cooperation with other arms of the Navy, or with the Army, against enemy vessels engaged in attacks on the coast.

"*Marine aircraft.*—The functions normally assigned to Army aircraft shall be performed by the marine aircraft when the operations are in connection with an advance base in which operations of the Army are not represented. When Army and marine aircraft are cooperating on shore, the control of their operations shall be governed by the one hundred and twentieth article of war, United States Army.

"The functions of aircraft assigned under Army (c) and Navy (e) are a duplication of functions. In such operations cooperation is vital to success. Such cooperation shall be governed by the following provisions:

"(a) The naval district forces, vessels and aircraft, will never be strong enough to prevent an attack on the coast by major units of the enemy fleet. When, therefore, an enemy force of a strength greatly superior to that of the naval force available for use against it approaches the coast the commander of the naval force shall inform the commander of the Army department of the situation; shall assume that the Army has a paramount interest in the operation, and shall coordinate the operation of the naval forces with those of the military forces.

"(b) If, however, the conditions are such that the enemy is, or can be, engaged by a naval force approximating in strength to that of the enemy, the commander of the Army department shall be so informed and he shall assume the Navy has a paramount interest in the operation and shall coordinate the operations of the military forces with those of the naval forces.

"The functions of aircraft above assigned shall govern in the production of aviation equipment, training of aviation personnel, and establishment of air stations for the War and Navy Departments. Such assignment shall not prevent the employment of Army and marine aircraft in naval functions upon the request of the senior naval officer present or vice versa, the employment of naval aircraft in Army functions upon request of the senior Army or marine officer present on shore; nor shall it prevent the employment of Army, Navy, or marine aircraft when no other Air Service is cooperating in the operation, in any manner which shall be most effective in accomplishing the mission of the force.

"All questions regarding the policy of the War and Navy Departments with regard to the tactical and strategical functions of aircraft, and to the location of air stations, shall be addressed to the joint board for consideration and recommendation to the Secretary of War and the Secretary of the Navy."

THE INCREASING IMPORTANCE OF AIRCRAFT IN WARFARE

The Limitation of Armaments Conference held in Washington in 1921-22 on invitation of President Harding examined into the possibility of limiting aviation development for war purposes and limiting the use of aircraft in warfare. A special committee of aviation experts representing the United States, Great Britain, France, Italy, and Japan was appointed. That committee submitted a report which reviewed the situation at length. The "final conclusions" of the report follow:

"The committee is of the opinion that it is not practicable to impose any effective limitations upon the numbers or characteristics of aircraft, either commercial or military, except in

the single case of lighter-than-air craft. The committee is of the opinion that the use of aircraft in warfare should be governed by the rules of warfare as adapted to aircraft by a further conference which should be held at a later date."

The fact that the Limitation of Armaments Conference placed no restriction on the development and application of aircraft for war purposes assures the greater relative importance of aircraft in future warfare. It is a maxim of military science that an army and a nation must be adaptable to changes in time of war. The best laid plans, whether for offensive or defensive warfare, are usually upset either by the success of the enemy or by changes and developments in the art of warfare. No one can foretell at this time what the use of aircraft will be in future wars, nor even in the next war. It is safe to say that there will be individual and group fighting in the air; there will be aircraft attacking troops on the ground, both with bombs dropped from great heights and with machine guns mounted on low-flying aircraft protected by armor from ordinary rifle bullets; there will be bombing of large cities, military and manufacturing centers, and routes of communication and transportation. And it has been proposed that aircraft be used to drop poisonous gases not only on the enemy's troops but also behind the lines and in the centers of population, to the same extent that long-distance bombing will be carried on. The bombs carried may not be limited to explosives and poisonous gases but may possibly be loaded with germs to spread disease and pestilence. Without limitations on the uses of aircraft in warfare a nation fighting with its back to the wall can not be expected to omit to use desperate means to stave off defeat. The uses of aircraft in warfare would then be limited only by the inability of human ingenuity to conceive further uses for this new agency of destruction.

A conference was held at The Hague in 1923, attended by delegates of the United States, which drafted rules and regulations covering the use of aircraft in war. There was evident a tendency to minimize as much as possible aircraft attack upon centers of population with the resulting consequences to noncombatants and to restrict such attacks to what are military objectives. In spite of the rules thus formulated, and even if they should be universally adopted, it is still inevitable that aircraft attacks would greatly terrify and undoubtedly seriously injure and damage many who have heretofore been classed as noncombatants.

It is believed quite probable that if the nations of the world do maintain adequate air forces, this may tend to the adjustment of international disagreements by conference, as the delegates to such conferences will have the strong backing of their national air forces capable of such destructive effect as that indicated above. When wars were fought within a limited territory by ground troops, the national patriotism of noncombatants strongly supported their armed forces, but in future wars when air power becomes a most vital factor in national defense, theaters of operation will no longer be limited to restricted territories, and noncombatants will probably and unavoidably be subjected to far greater personal danger and injury than in the past. It is not inconceivable that such pressure will be brought to bear upon the Governments concerned by their noncombatants, following a series of aircraft raids, that an early cessation of hostilities will be more earnestly desired by the people on both sides and will be forced by popular demand upon the nation least efficient in air power.

Aviation has made itself indispensable to military and naval operations. Under our present organization, where the function of national defense is vested principally in the War and Navy Departments, we must look to those departments to develop the possibilities of aviation in warfare, whether to be used in conjunction with military and naval operations, or to be used independently for attacking distant points behind the enemy's lines, or elsewhere. The problem of the air defense of this country is worthy of most careful study.

RELATION OF AERONAUTIC RESEARCH TO NATIONAL DEFENSE

So long as the development of aviation continues from year to year, the military and naval policies and programs for our national security and defense are necessarily subject to change, as they are largely dependent upon the probable use of aviation in future wars. So long as other nations are seriously engaged in the development of aviation, America must at least keep

abreast of the progress of aviation abroad and never permit itself again to fall behind as it did before the World War. Substantial progress in aviation, whether in America or elsewhere, is in the last analysis dependent upon aeronautical research. It is necessary that accurate information, which is the result of scientific research on the fundamental problems of flight, should be made continuously available to the Army and Navy; and those agencies desire from the National Advisory Committee for Aeronautics the fundamental aerodynamic information on which the design of new types of military and naval aircraft is based. It is the function of the Army and Navy then to check this information and apply it in an engineering manner to the design of aircraft.

While national defense is the greatest use to which aircraft is applied in America to-day, the committee believes that the time will come when its military uses will be second in importance to its civil value in promoting our national welfare and increasing our national prosperity. But to-day, while the uses of aircraft are primarily military and the Air Services of the Army and Navy are not as large as those of other world powers, America is gradually forging ahead of other nations in the acquisition of knowledge of the scientific principles underlying the design and construction of aircraft. To this important but limited extent we are providing well against unpreparedness in the air.

THE AIRCRAFT INDUSTRY AND ITS RELATION TO NATIONAL DEFENSE

The present American aircraft industry is but a shadow of that which existed at the time of the armistice. With the great stimulus in aircraft development and performance during the war, the aircraft manufacturers were hopeful that civil aviation would rapidly come into being with a resulting great demand for their product. Civil aviation has not developed as it was hoped it would, and this makes the present situation more difficult.

These aircraft manufacturers have had to rely for orders upon Government agencies, and the limited amount of governmental purchases has forced a number of manufacturers to go out of the aircraft business. It is a matter of grave Government concern lest the productive capacity of the industry may become so far diminished that there may not remain a satisfactory nucleus. By a "satisfactory nucleus" is meant a number of aircraft manufacturers, distributed over the country, operating on a sound financial basis, and capable of rapid expansion to meet the Government's needs in an emergency.

After the very costly lessons of the war, it would be folly to say that the Government is not concerned with the state of the aircraft industry. It is concerned that there should be in existence, and in a healthy condition, at least an adequate nucleus of an industry. An aircraft industry is absolutely essential to national defense. One lesson of the war that will not be forgotten is that it takes a great deal of money to develop hastily an aircraft industry from almost nothing. The American people can ill afford to pay such a price a second time. To maintain a nucleus of an industry it has been proposed either that the Government substantially increase the volume of its orders for aircraft or devise a policy for the apportionment of orders at fair negotiated prices without regard to competition.

Neither of these propositions, however, in the judgment of the National Advisory Committee for Aeronautics, goes to the root of the trouble. To substantially increase orders will require substantially increased appropriations. To increase appropriations for the Army and Navy Air Services because they need more aircraft is one thing, but to increase appropriations primarily to maintain an aircraft industry is something else. Furthermore, the maintenance of an industry in a healthy condition does not involve the maintenance of any manufacturer who has failed to liquidate or reduce his plant and overhead expenses to an appropriate peacetime basis.

In the judgment of the committee, the existing bad situation in the industry should be substantially remedied. In an effort to help the situation, the committee suggests the following steps on the part of the industry and of the Government:

Steps to be taken by the industry:

First. Every manufacturer intending to remain in the aircraft business and who has not readjusted his war-time plant and overhead expenses to a peace-time basis should do so without further delay.

Second. The firms comprising the aircraft industry should specialize in the production of various types of aircraft with a view to the more continuous development of types by the same plants and the gradual recognition of proprietary rights in new designs.

Steps to be taken by the Government:

First. The Army, Navy, and Postal Air Services should agree upon a balanced program setting forth from time to time the probable requirements of the Government for each type of aircraft for at least one year in advance, and should announce the same to the industry for its information and guidance.

Second. Orders for the different types should be placed with the different manufacturers at such intervals as to insure continuity of production and the gradual development of special facilities and skill by each manufacturer in the production of a given type of aircraft.

The committee does not attempt to say that the method proposed is the ideal solution, but it submits that if followed it would produce the following beneficial results:

- (a) It would insure the continuous development of types by the same firms which is the most rational method of improving the quality and performance of aircraft to meet special needs.
- (b) It would reduce the cost of aircraft.
- (c) It would provide all manufacturers with an adequate market to enable them to continue in the airplane business without the periodical menace of dissolution or bankruptcy heretofore caused by long gaps, between orders.

COMMERCIAL AVIATION AND ITS RELATION TO THE GOVERNMENT

The stimulus of war forced the development of aviation for military purposes, and while the progress thus made was beneficial to all aviation, nevertheless there has been but little application of aviation to commercial purposes. In England, France, Italy, Germany, Holland, Belgium, Poland, and other European countries there are air lines for the transportation of passengers and goods on regular schedules across international boundaries and intervening seas. It is quite a customary thing for tourists and business men to travel by air, for example, between London and Paris. There is a great rivalry for business between French and English companies, all of which are subsidized by their Governments.

There is at the present time in the United States no large regular air transportation business, although enterprising firms from time to time have undertaken to establish more or less regular routes between points deemed peculiarly attractive for the development of an air transportation business. The Air Mail Service operated by the Post Office Department has given the best and most practical demonstration of the reliability and adaptability of aircraft to the useful purposes of commerce. The present experiment by the Air Mail Service to determine the practicability of night flying is the most important development in aviation to-day and should prove to be of substantial assistance in the development of commercial aviation in America.

The reason for the greater development of commercial aviation in European countries to date lies in the fact that they realize more keenly than we in America do the vital necessity of

aviation to national defense. They are either adjoining neighbors or within a few hours of each other by air, and unless military aviation in those countries is to bear the entire cost of the maintenance of aircraft industries and of aviation development generally, those countries must in sheer self-defense encourage commercial aviation. This they have done in every practicable way, principally by subsidizing common carriers by air, especially those engaged in international aerial transport.

In the United States direct subsidy appears to be out of the question because of our adherence to a traditional policy. In our country aviation must make its own way. Civil aviation has not progressed very far because it has not yet reached that stage of development that justifies its use generally from an economic point of view, unless an inordinate value is to be placed upon speed. Speed and maneuverability may be prime factors in military aircraft, especially in time of war, but for commercial purposes aircraft must be made safer, more controllable at low speeds incident to taking off and landing, and less expensive in initial cost as well as in maintenance and operation.

Commercial aviation will have to be regulated, just as are other means of transportation. The initial legislation in this respect should be very carefully prepared, so that, while affording that degree of regulation considered necessary in the public interest and that degree of practical assistance that would be helpful, it will nevertheless leave the new art of aviation ample freedom to develop normally without unnecessary or unwise restrictions and without attempting to set up by legislation an artificial basis for the maintenance of the activity to be regulated.

SUMMARY

Aviation has been proved indispensable to both the Army and the Navy. Neither can operate effectively without an adequate air service. What was considered adequate in the World War will not do in the future.

The progress in scientific research and in the technical development of airplanes and airships has been continuous and gratifying; but before commercial aviation can become self-supporting airplanes must be made safer, more controllable at low speeds incident to taking off and landing—where most accidents occur, and less expensive in initial cost and in the cost of maintenance and operation.

Although the problems of rigid and semirigid airships have been seriously studied during the past two years, there is much to be learned about airships. In the present state of development of rigid airships, as exemplified by the remarkable flights of the *Shenandoah* from Lakehurst, N. J., to Seattle, Wash., and return, and of the *Los Angeles* from Friedrichshafen, Germany, to Lakehurst without stop, it is evident that matériel has reached the point where, with practice and experience, the possibilities in the field of commercial airship transportation can be determined.

The aircraft industry is in a poor condition, but the remedy is within the control of the manufacturers and the governmental agencies concerned. The committee has proposed a basis for solution of the existing difficulty.

In view of all the circumstances at present affecting the development and use of aeronautics in America and its relation to the public welfare and national defense, the National Advisory Committee for Aeronautics submits the following:

GENERAL RECOMMENDATIONS

1. *Scientific research.*—The continuous prosecution of scientific research on the fundamental problems of flight should be regarded as in the last analysis the most important subject in the whole field of aeronautical development, as substantial progress in aeronautics depends upon the continuous acquisition of knowledge which can be obtained only by long-continued and well-directed scientific research.

2. *Air Mail Service.*—The Air Mail Service should be continued under the Post Office Department and its ground equipment for night flying should be extended to cover the entire route between New York and San Francisco. When this is done, overnight transportation of

mail by aircraft between strategic points, as for example, between New York and Chicago, should be provided at rates that will make such service eventually self-supporting.

3. *Commercial aviation.*—Rapid development of commercial aviation is primarily dependent upon increasing the reliability and economy of operation of aircraft. Other countries, notably England and France, have encouraged commercial aviation by direct subsidies, and their experience has indicated that unless governmental aid is given, directly or indirectly, commercial air transportation can not be financially successful in the present state of aviation development. Legislation providing for the reasonable regulation of aircraft, airdromes, and aviators, and affording necessary aids to air navigation along designated national airways would be most helpful. The establishment of landing fields generally would also stimulate improvement in the reliability and economy of aircraft operation and facilitate the development of commercial air transportation in this country on a sound basis.

4. *Military and naval aviation.*—There should be continued study of the air defense problem of the United States, and continued support of aviation development in the Army and Navy.

CONCLUSION

The investigation and study of the fundamental phenomena of flight is the most important subject in the whole field of aeronautic development and is the definite prescribed function of the National Advisory Committee for Aeronautics. It has been a great pleasure to the committee to note that the importance of scientific research is appreciated more generally, and that the Congress, the President, and the Bureau of the Budget have recognized the need for the effective prosecution of the research programs prepared for the advancement of the science of aeronautics.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
JOSEPH S. AMES, *Chairman Executive Committee.*